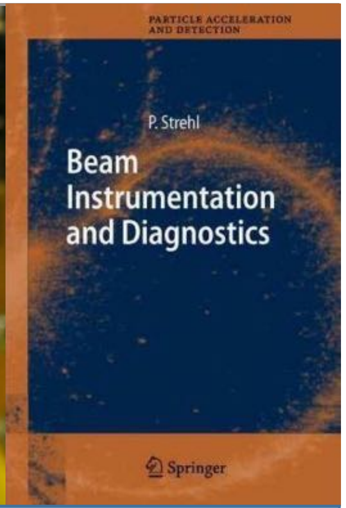
IOP Institute of Physics

PABG Annual Conference

25th - 26th July 2022 | Liverpool



Accelerator Diagnostics Overview

John Adams Institute for Accelerator Science

Stephen Gibson

ROYAL HOLLOWAY UNIVERSITY OF LONDON

With a big thanks to collaborators

S. Alden, A. Arteche, D. Bett, E. Bravin, S. Burger, P. Burrows, D. Butti, A. Bosco, A. Goldblatt, H. Guerin, R. Jones, P. Karataev, M. Krupa, T. Hofmann, T. Lefevre, S. Levasseur, T. Levens, A. Lyapin, L. Nevay, S. Mazzoni, C. Pakuza, F. Roncarolo, B. Spear, J. Storey, C. Welsch, H. Zhang et al

Overview

- ***Motivation of intense hadron beam diagnostics***
  - ***From Liverpool to CERN***
- ***Recent upgrades CERN beam instrumentation***
  - ***Fast wire scanners and CNT tests***
  - ***Linac4 laserwire***
  - ***PS Beam Gas Ionisation***
- ***Diagnostics in development for HL-LHC:***
  - ***Profile monitors: Beam Gas Curtain, Beam Gas Vertex***
  - ***Halo: synchrotron light monitor***
  - ***Bunch direction: Interaction Region BPMs***
  - ***Bunch shape & instability: Electro-Optics BPMs***
- ***Linear Colliders & AWAKE***
  - ***Cherenkov diagnostics for AWAKE***
  - ***Electron beam diagnostics, cavity BPMs, fast feedback.***

Liverpool's synchrocyclotron

- ***Fun fact: the space next to the crypt where our conference dinner was held last night, used to house a synchrocyclotron, which operated from 1954 to 1968.***

- https://physicsworld.com/a/the-legacy-of-liverpools-forgotten-synchrocyclotron/

Beam extraction from Liverpool's synchrocyclotron

Machine pioneered in 1946 by Sir James Chadwick & Joseph Rotblat:

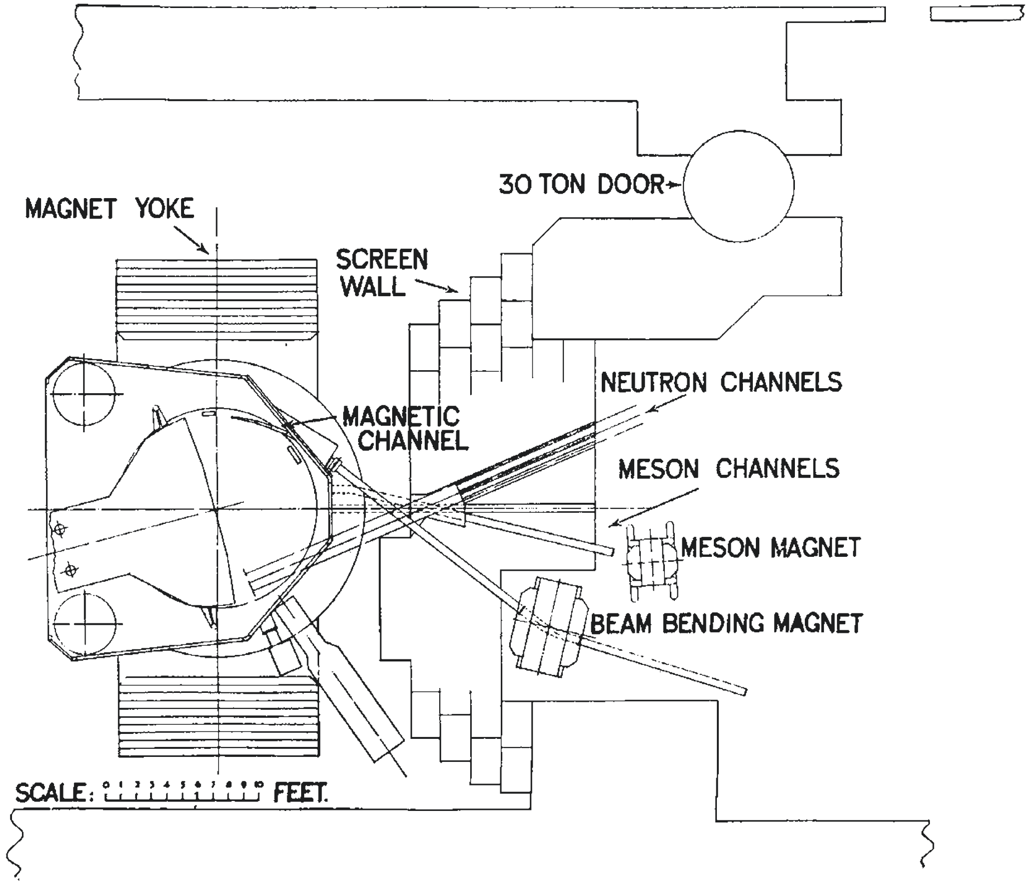


Fig. 1. Plan of cyclotron showing disposition of some of the associated apparatus

- *"You can keep sending the stuff round and round. But unless you can get it out, hitting something, it's no use," P. Rowlands*

Moore, M. *The 156-in. Cyclotron at Liverpool Nature* **175,** 1012–1015 (1955). https://doi.org/10.1038/1751012a0

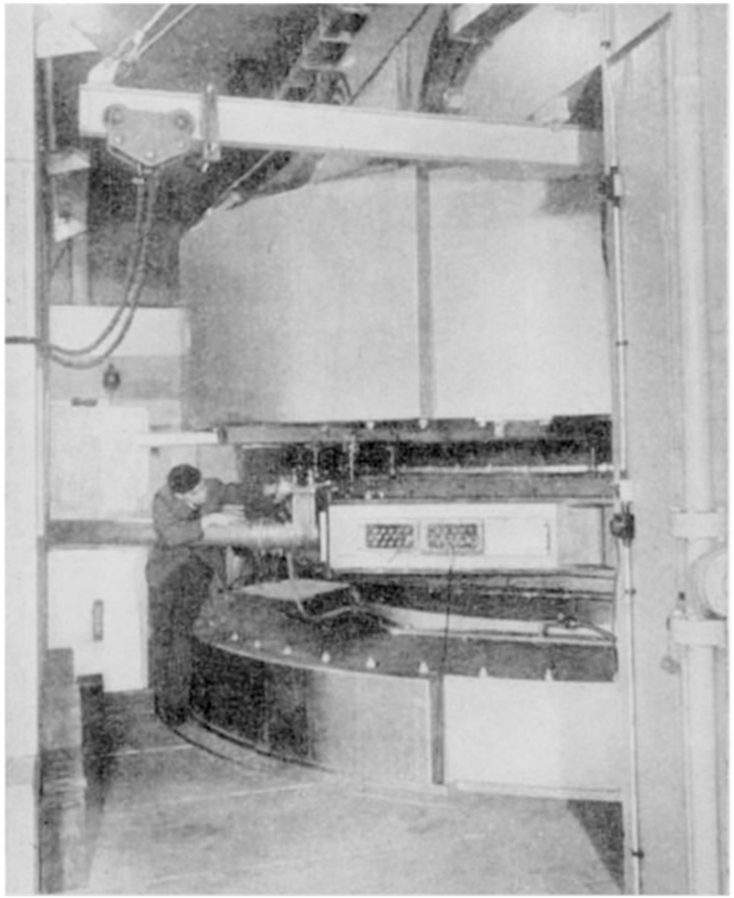


Fig. 4. The beam-exit side of the cyclotron, showing the 6-in. diameter proton tube leaving the vacuum tank and passing through the dense screen wall on the left

Historic diagnostics at Liverpool's synchrocyclotron

- ***A major achievement was to extract 10-20% of the 383 MeV proton beam; 3% reaching the experiment room.***
- ***The beam was imaged by exposing to printing paper for 1 min: Liverpool's first beam profile measurements!***

Flux: 10^{10} protons/cm^2/sec

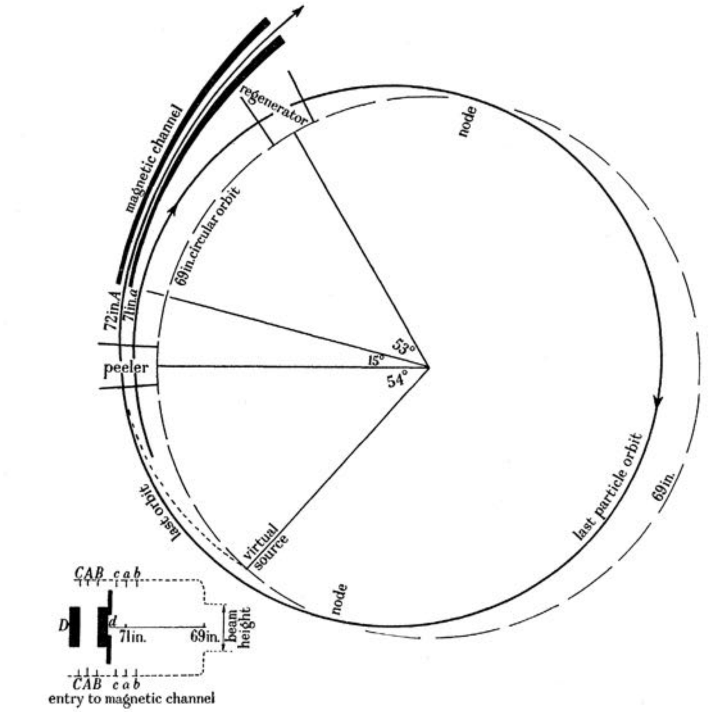


FIGURE 2. General layout of the extraction system showing the final particle orbits and conditions at the entry to the magnetic channel.

plane. After optimizing the position of peeler and regenerator, the main cyclotron field, and median plane, 20% of the circulating beam was found to be entering the channel. This was measured by comparing the activity of carbon blocks placed in the mouth of the channel with that on a carbon flip target. The number of

The external beam travels 15 ft through a channel in the screening wall, and appears in the experimental room spread over an area of about 10 sq in. Figure 1 shows two pictures of the beam taken by exposing printing paper to the beam for 1 min. The upper photograph is taken at the end of the magnetic channel ($1\frac{1}{2}\times2\frac{1}{2}$ in. in area), and the lower one is a composite picture of the beam in the experimental room 15 ft from the end of the channel.

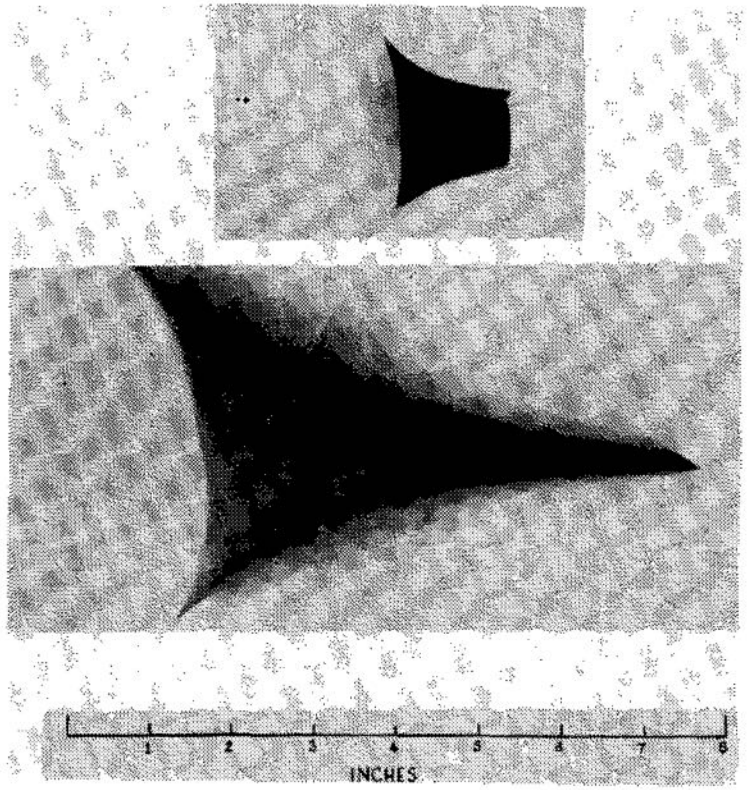


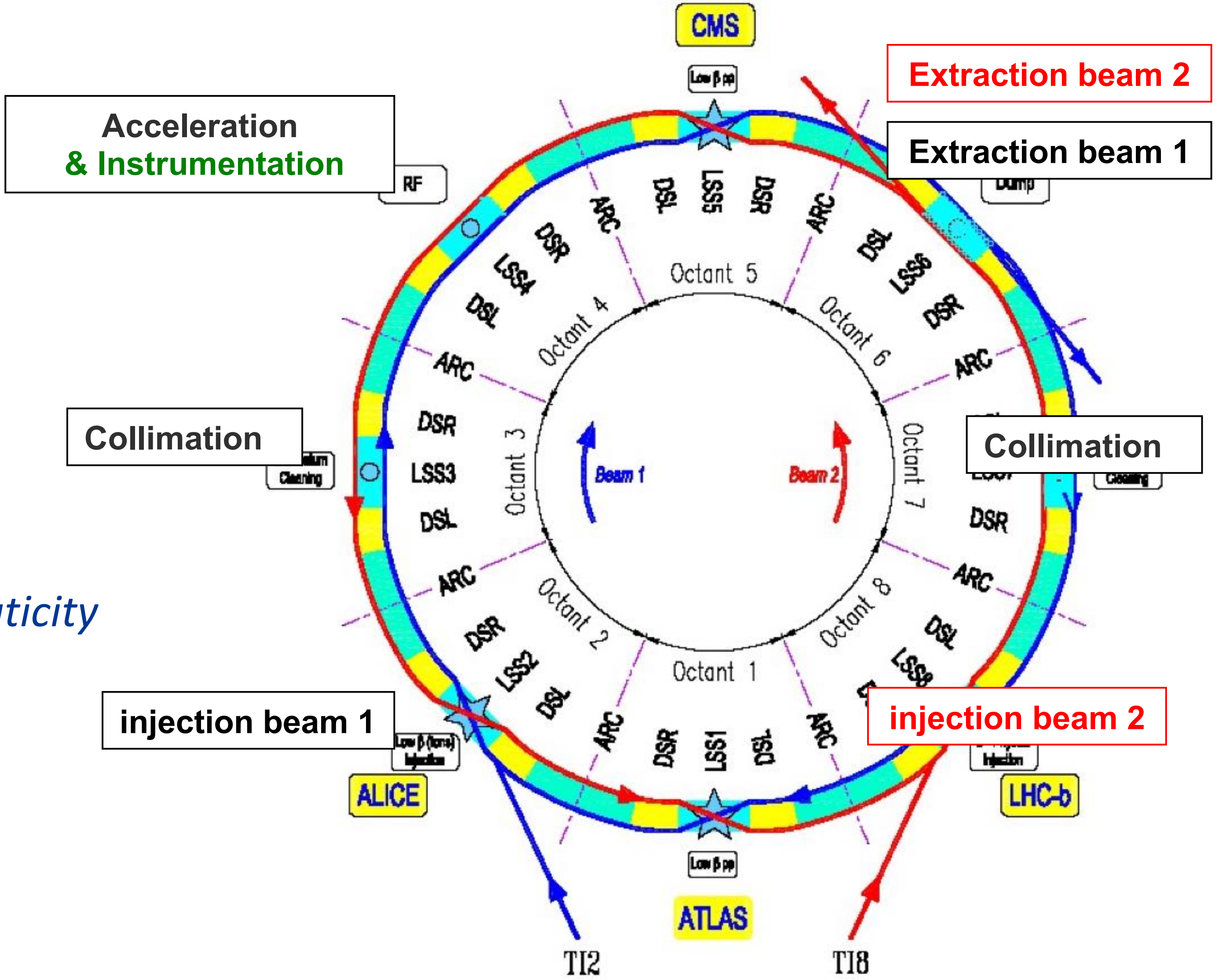
FIG. 1. Cross section of the beam (top) at the exit of the magnetic channel and (lower) in the experimental room about 15 ft away.

Le Couteur, K. J., *The Extraction of the Beam from the Liverpool Synchrocyclotron. Proc. of the Royal Society of London* **232**, 1189 (1955): 236–41. http://www.jstor.org/stable/99763

Crewe, V. & Le Couteur, K. J. *Extracted Proton Beam of the Liverpool 156-Inch Cyclotron* Rev. of Sci. Inst. **26**, 725 (1955); https://doi.org/10.1063/1.1715295

Beam instrumentation at the Large Hadron Collider

- *1182 beam position monitors*
- *>4000 beam loss monitors*
- *Screens at injection and extraction*
- *Wire scanners, synchrotron radiation monitors*
- *Monitors for current, tune and chromaticity*
- *Bunch instability monitors*
- *Luminosity monitors*



T. Lefevre

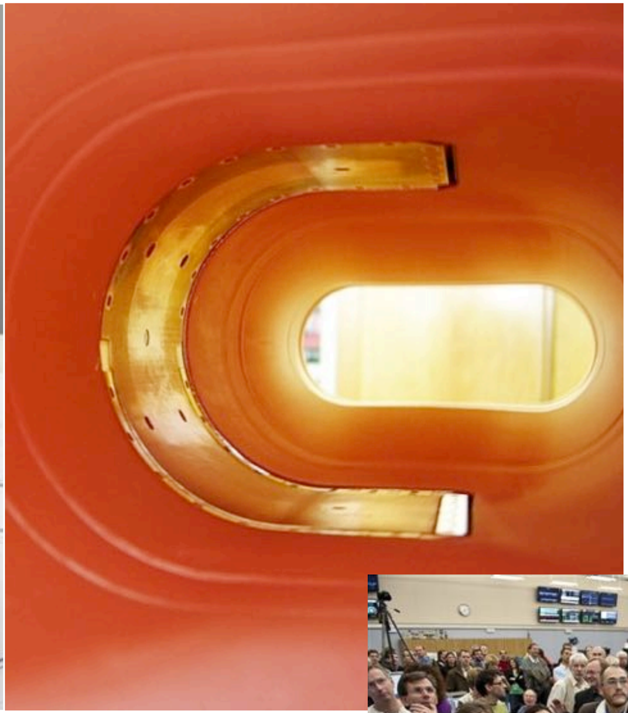
First beam circulation at LHC

- ***Diagnostics crucial for rapidly steering beam 1 from point 2 to point 3 & 5 & 6 & 7 & 8!***

1182 beam position monitors

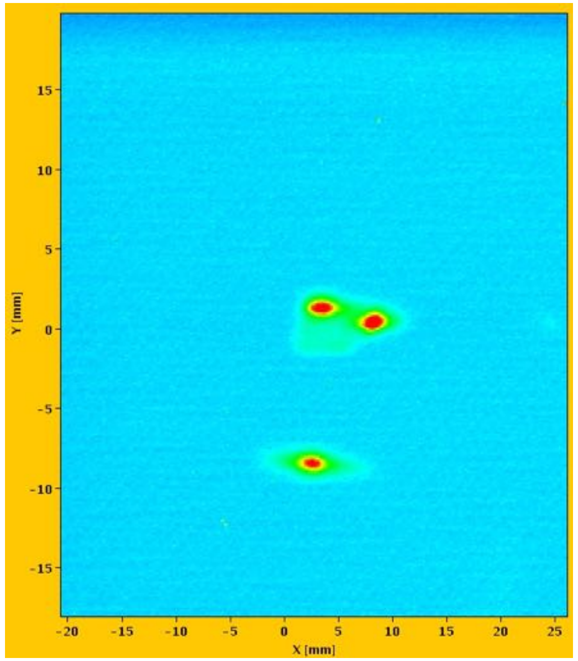
Historic diagnostics: first beam at LHC

- ***Interceptive scintillation-screen diagnostics are still widely used today, e.g. at LHC injection & first circulation:***

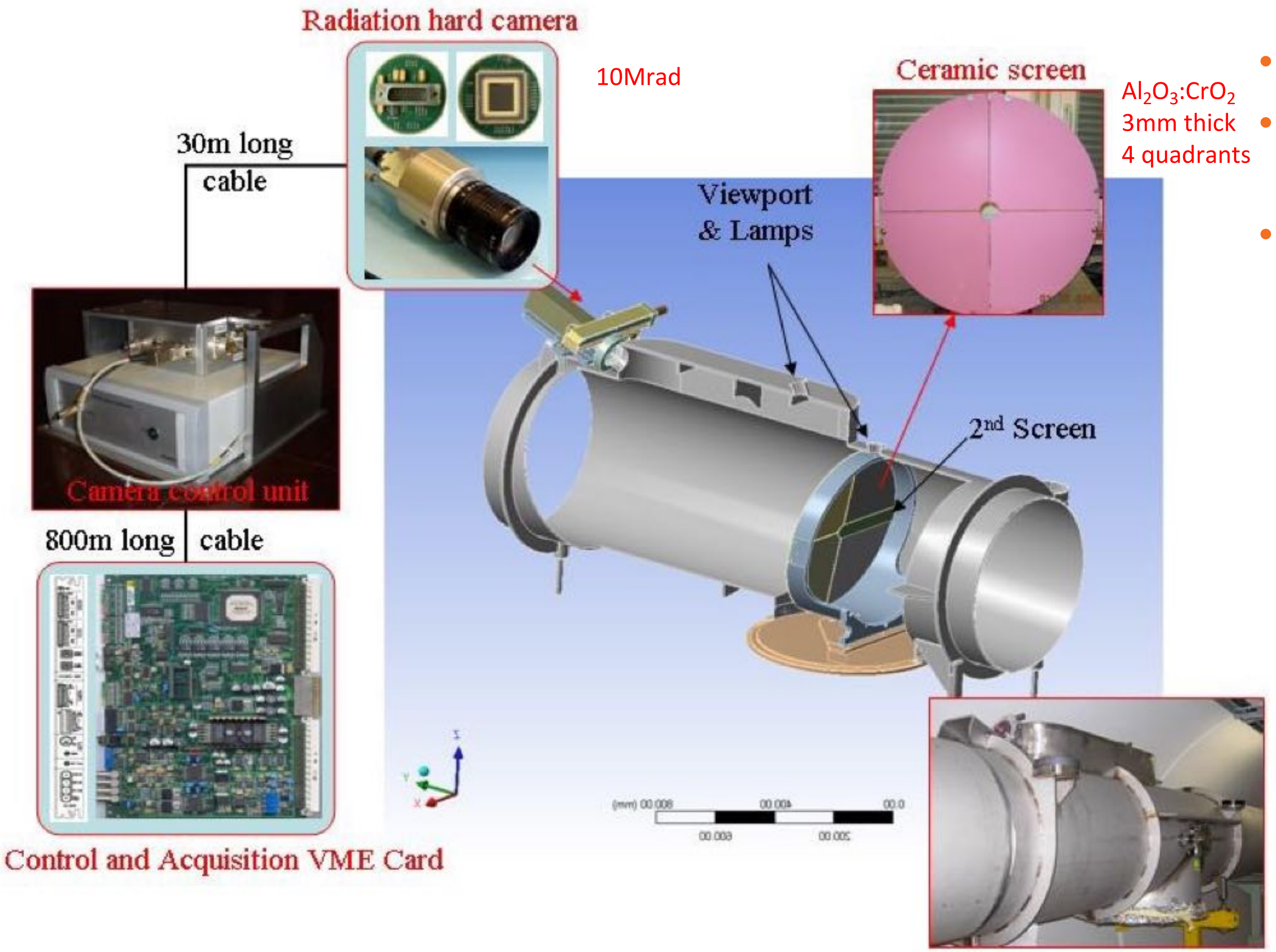


Chromox screen and camera installed just after injection

Observe first turns of LHC:



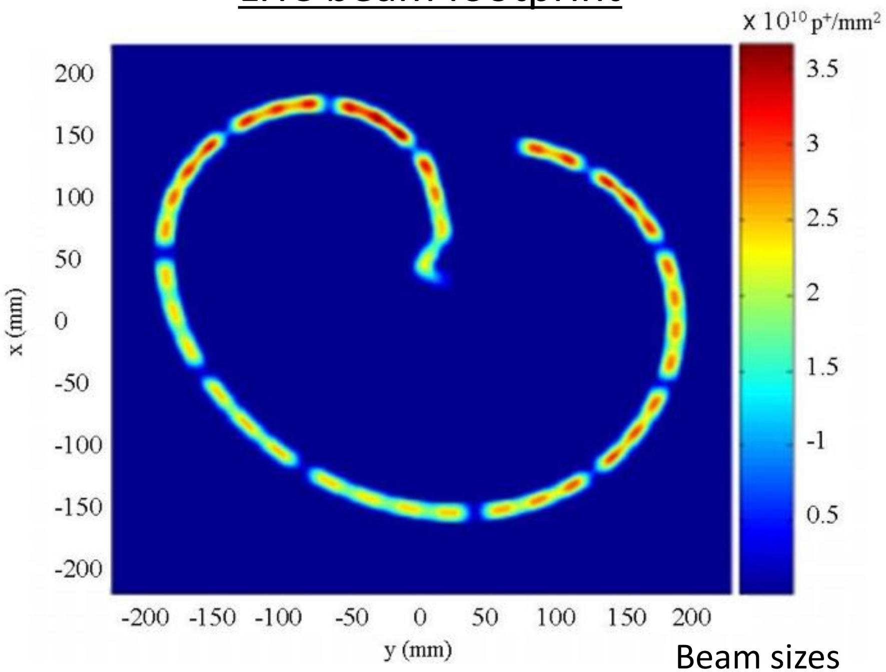
- ***Interceptive scintillation-screen diagnostics are still widely used today, e.g. at LHC extraction to beam dump:***



T. Lefevre et al, 'A large scintillating screen for LHC dump line', DIPAC 2007

- *~360MJ of beam energy must be absorbed without damage;*
- *The beam density is reduced from ~10^{15} p+/mm^2 to ~10^{11} p+/mm^2 by a 900m beam line of fast magnets.*
- *Measure the dilution of the beam 30m before the final absorber*

<u>LHC beam footprint</u>



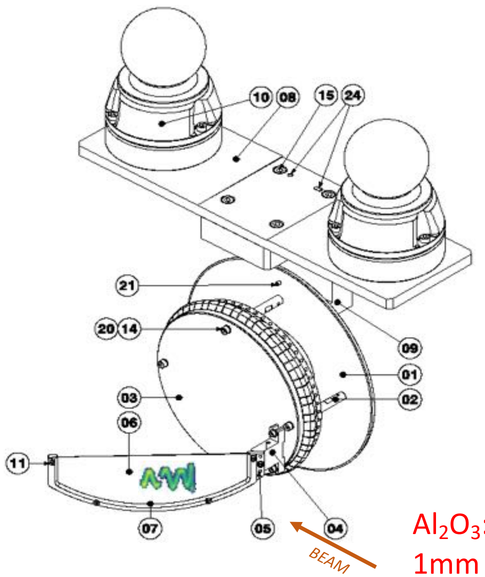
Beam sizes

- 6mm@450GeV
- 1.2mm@7TeV

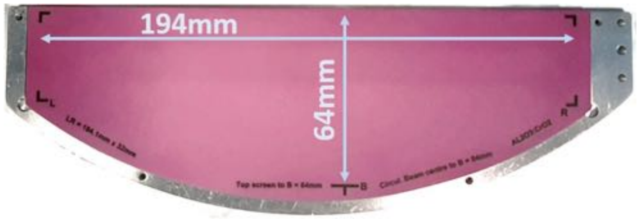
New CERN SPS beam dump imaging system

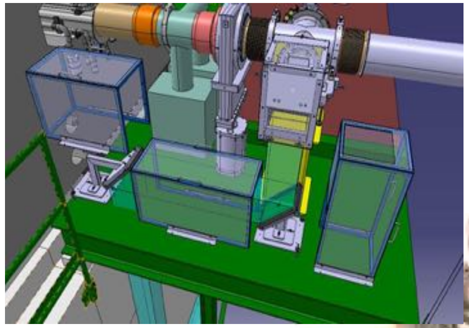
- ***Interceptive scintillation-screen diagnostics are still widely used today, e.g. SPS beam dump imaging***

Screen underneath circulating beam

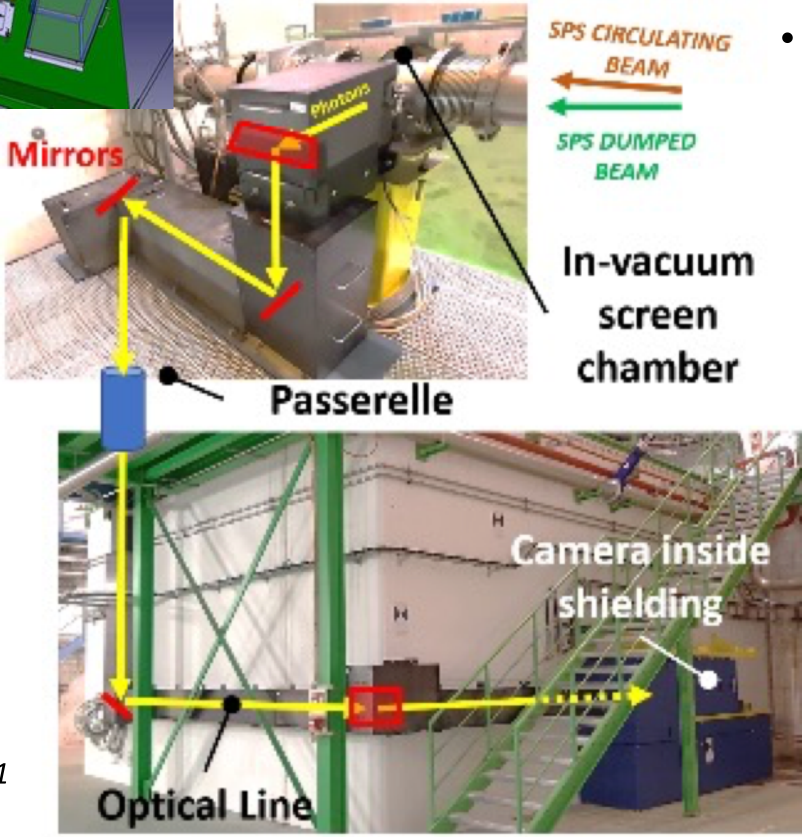


$Al_2O_3:CrO_2$
1mm thick

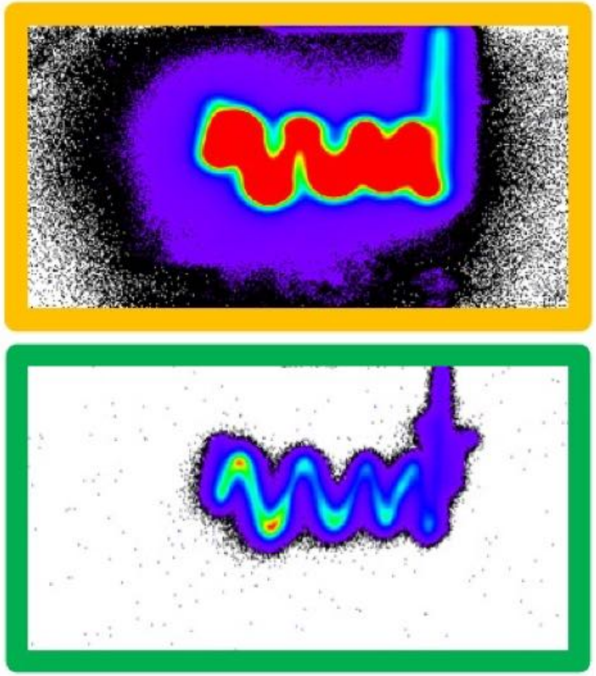




Chromox screen imaged via 17m optical line



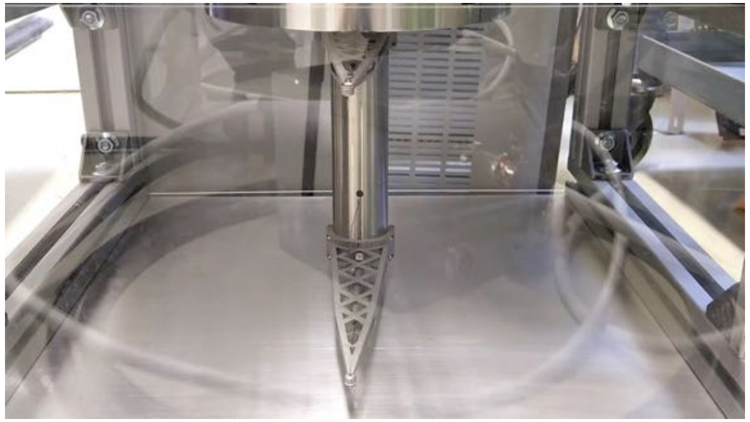
- Chromox light yield decays slowly (> few 100ms), so acquisition system records several images after each dump event.
- Online SW selects non-saturated images, with the saturation level depending on beam intensity, size and dilution strength

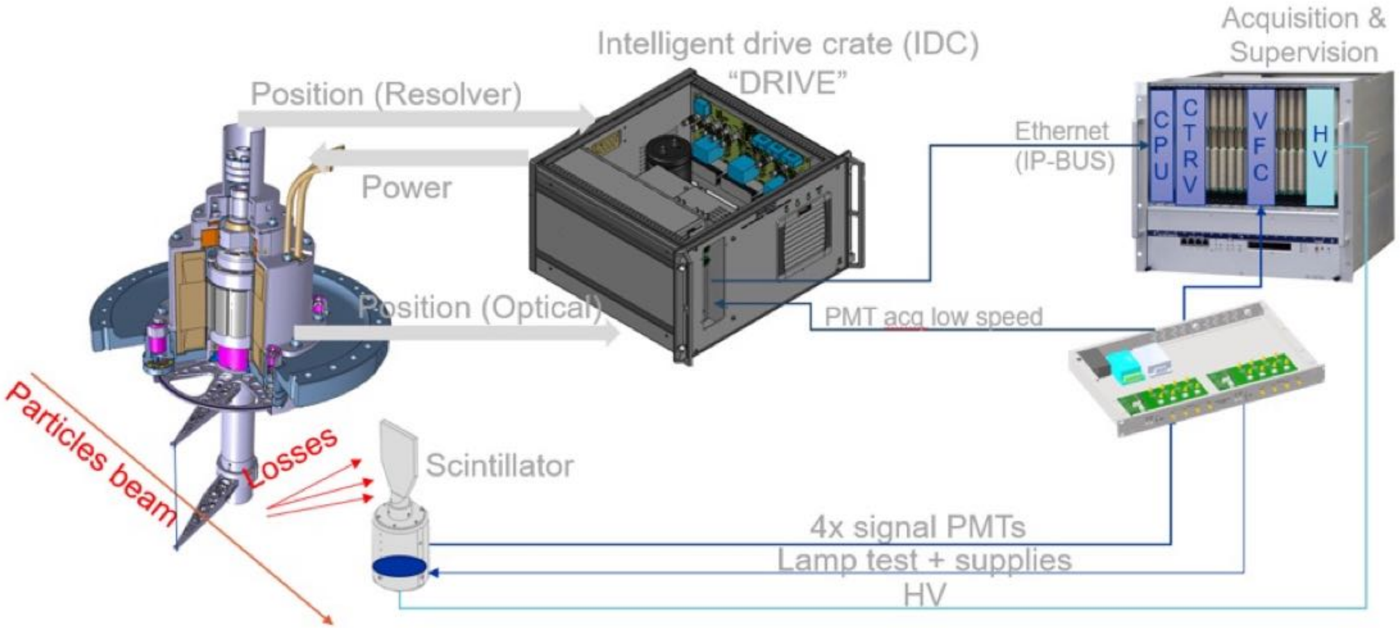


S. Burger et al, 'New CERN SPS Beam Dump Imaging System', IBIC 2021

New fast wire scanners in the PSB, PS and SPS

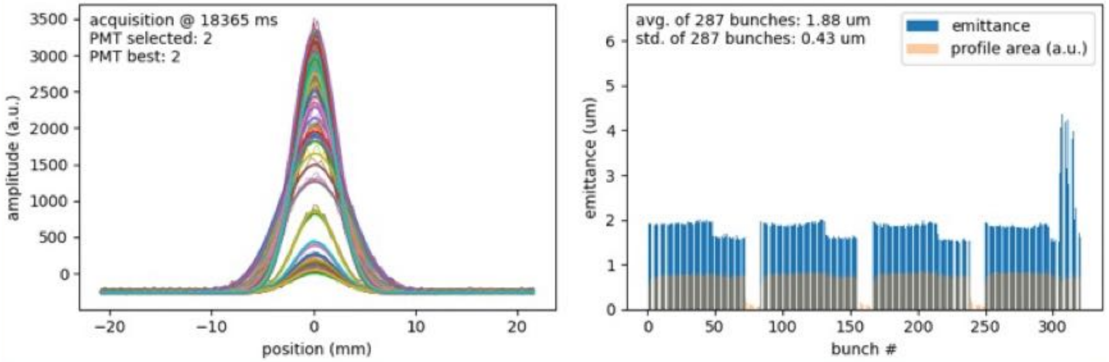
- *17 scanners installed in 2020 (+ 5 units built for ESS)*
- *20 m/s rotation speed, with wire position recorded by an optical encoder*
- *Downstream scintillators/PMTs record secondary particles*
- *500MS/s digitisation to enable bunch by bunch measurement*





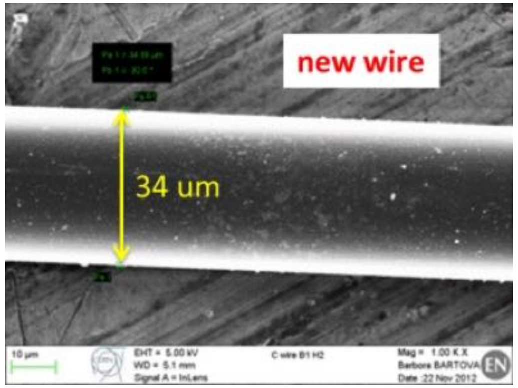
Optical encoder disk

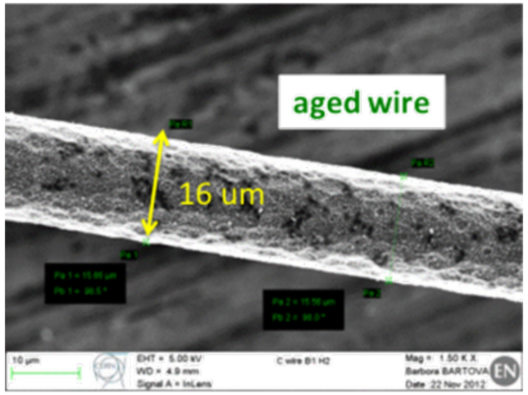
SPS bunch by bunch measurements:



Limitations and R&D on wire scanners

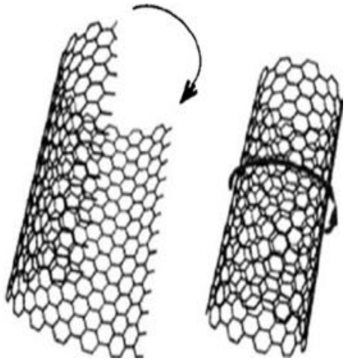
- *Wires age from sublimation damage, used at modest beam currents / number of bunches and for calibration of non-invasive diagnostics.*



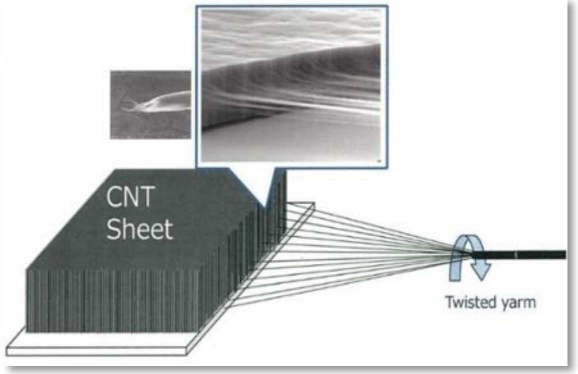


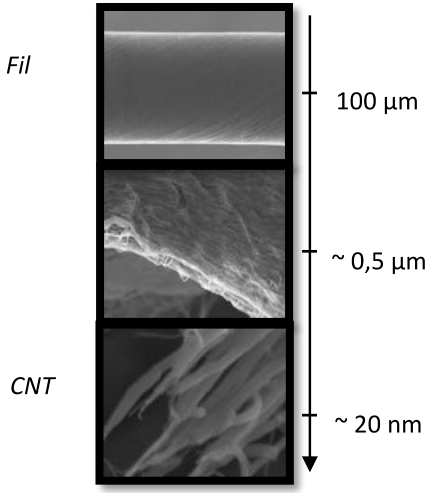
[1] Sapinski, M., J. Koopman, E. Métral, A. Guerrero, et B. Dehning. « Carbon Fiber Damage in Accelerator Beam ». CERN Document Server, 1 mai 2009. https://cds.cern.ch/record/1183415.

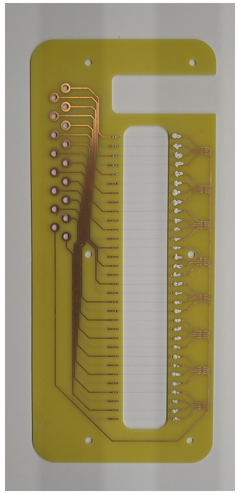
R&D on the material choice for the wire

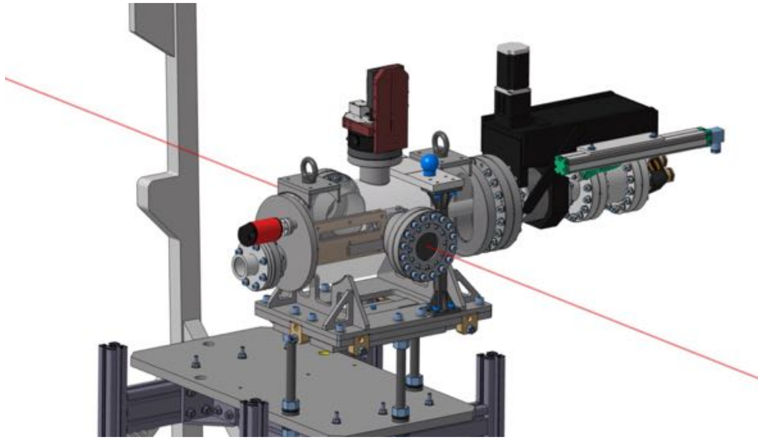


Graphene wires: 'Carbon Nano-Tubes' (CNT)









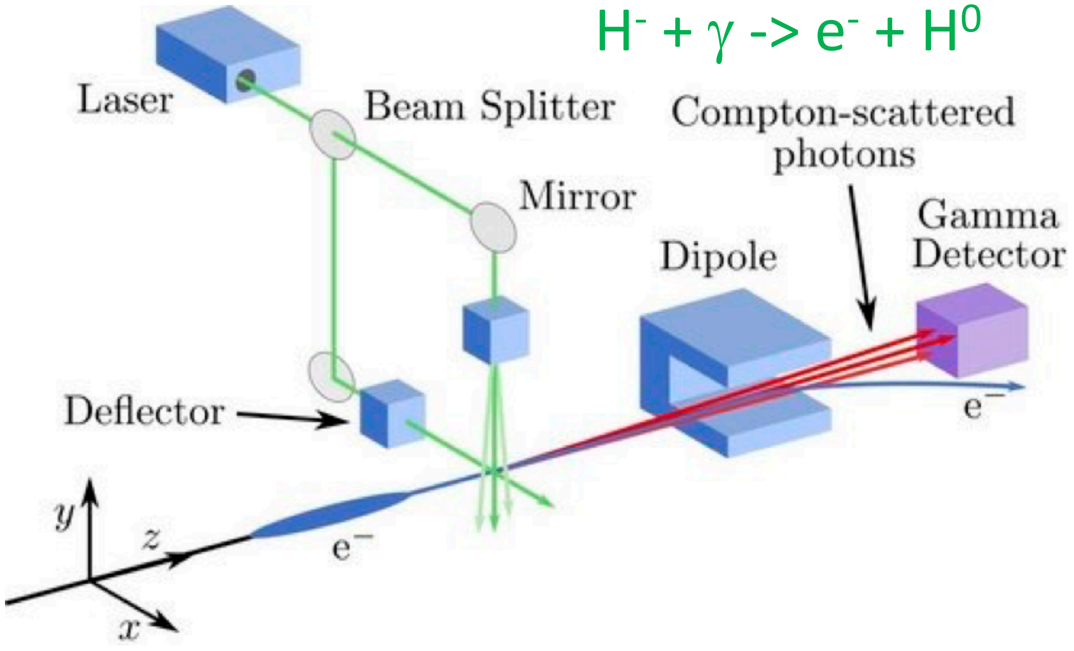
Test of CNT wire in HiRadMat CERN in 2021

Non-interceptive diagnostics: laserwires

Replace the *wire* with a *laser beam:*

- **Electron beam laserwires**:
  - detect Compton-scattered photons
- **Hydrogen ion beam laserwires:**
  - detect product(s) of photo-detachment

$H^- + \gamma \rightarrow e^- + H^0$



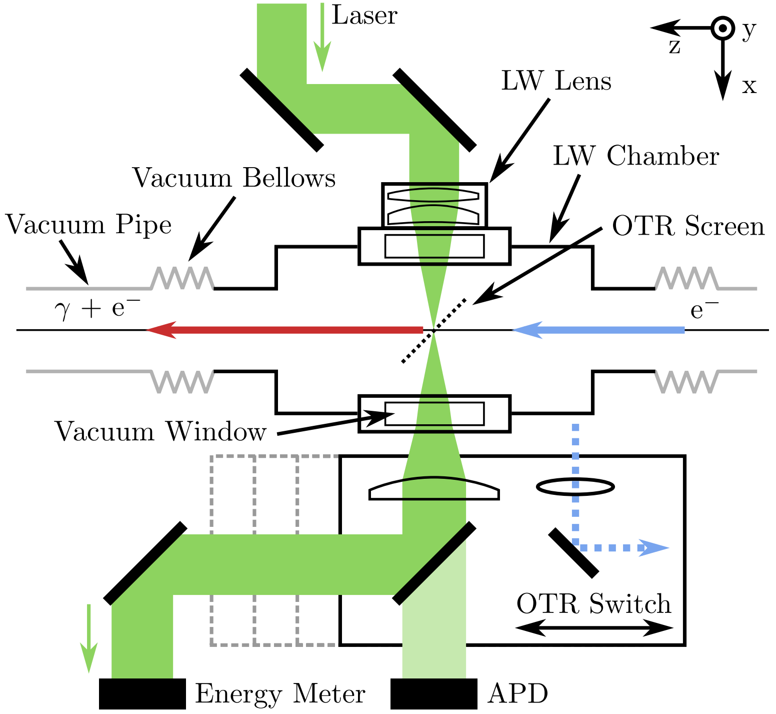
A **laserwire beam diagnostic** operates by shining a narrow laser beam transversely through a particle beam. Particles interact with the light, via Compton scattering for electron laserwires or by photodetachment ($H^- + \gamma \rightarrow H^0 + e^-$) for hydrogen ion laserwires.

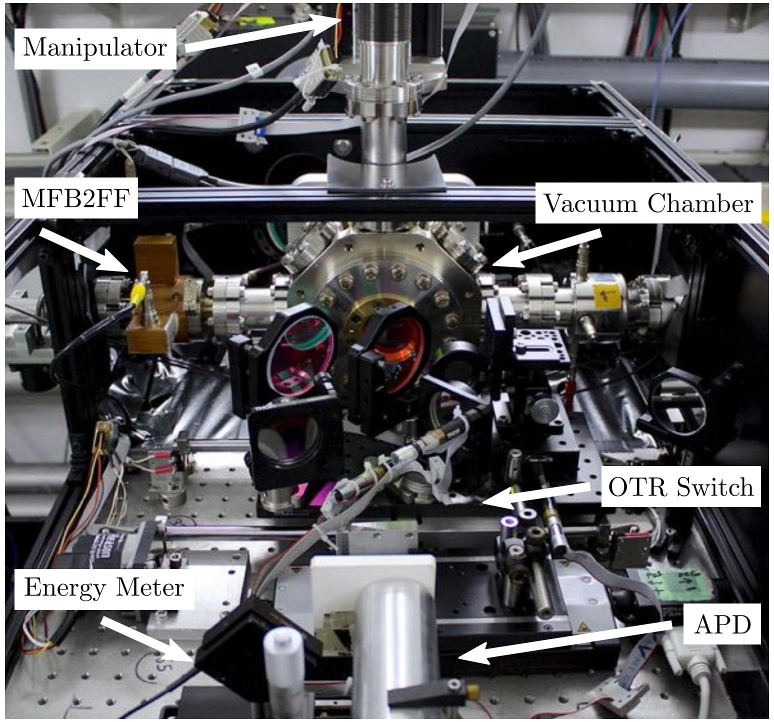
- *Laserwire advantages:*
  - *Non-interceptive, so no mechanical damage to wire*
  - *Continuous measurement during beam operation*
  - *Minimally invasive: only a tiny fraction of the particle beam is neutralised / scatters.*
  - *Emittance reconstructed using segmented detector*
  - *A pulsed laser enables access to longitudinal as well as transverse beam information*
  - *Micron scale beams measurable (see next slide)*

e- laserwire at ATF2:

- Light focused into interaction chamber through vacuum window required careful optics design to deliver beam with minimal aberrations:

Successful measurement of the 1.07 μm profile electron beam!





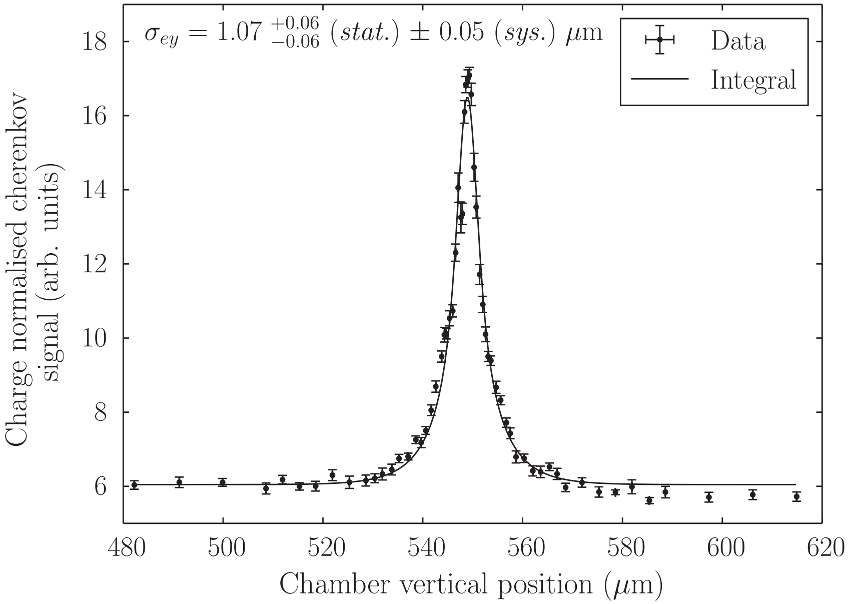


FIG. 19. Nonlinear step size laserwire scan with the smallest measured electron beam size.

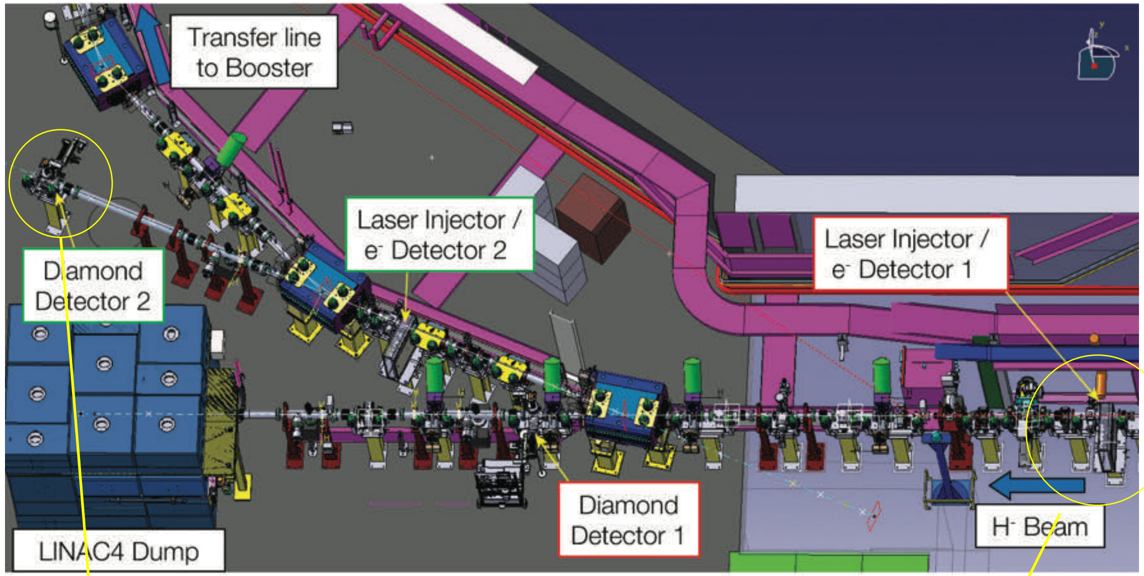
A. Aryshev, S. Boogert L. Corner, D. Howell, P. Karataev, K. Kruchinin, **L. Nevay**, N. Terunuma, J. Urakawa, R. Walczak

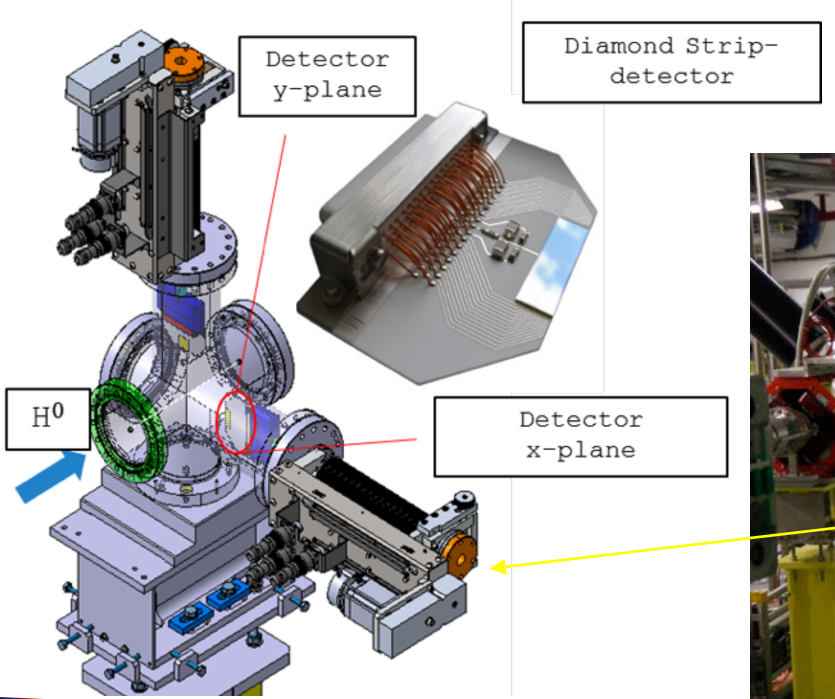
L. Nevay *et al: Laserwire at the Accelerator Test Facility 2 with submicrometer resolution*
Phys. Rev. Special Topics - Accel. Beams, 17, 072802 (2014)

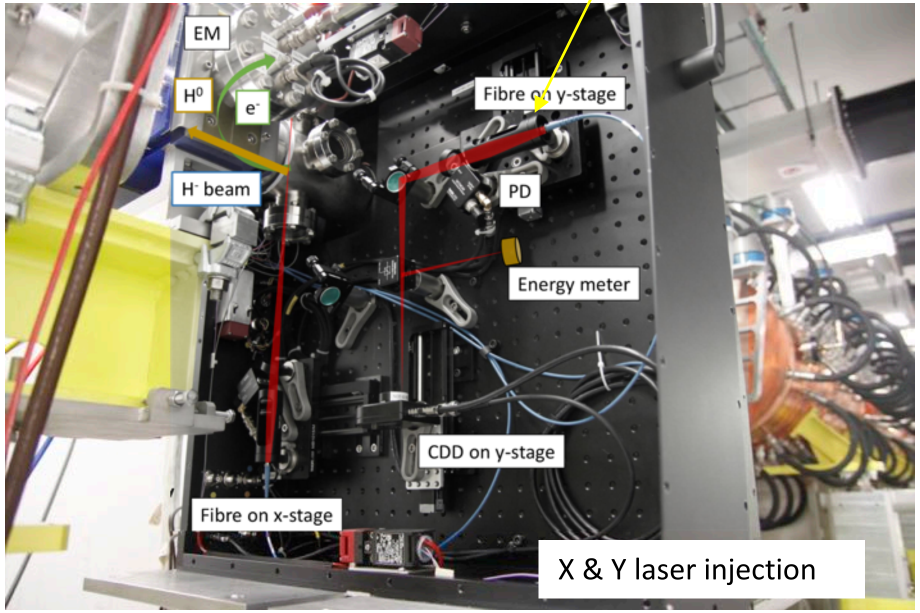
Dual laserwire installed at Linac4

T. Hofmann et al

- ***Non-interceptive emittance monitor***
  - *4 laserwires: in X and Y at two locations.*
  - *Commissioned in 2018 at 160 MeV*
  - *Multi-channel diamond strip-detector*



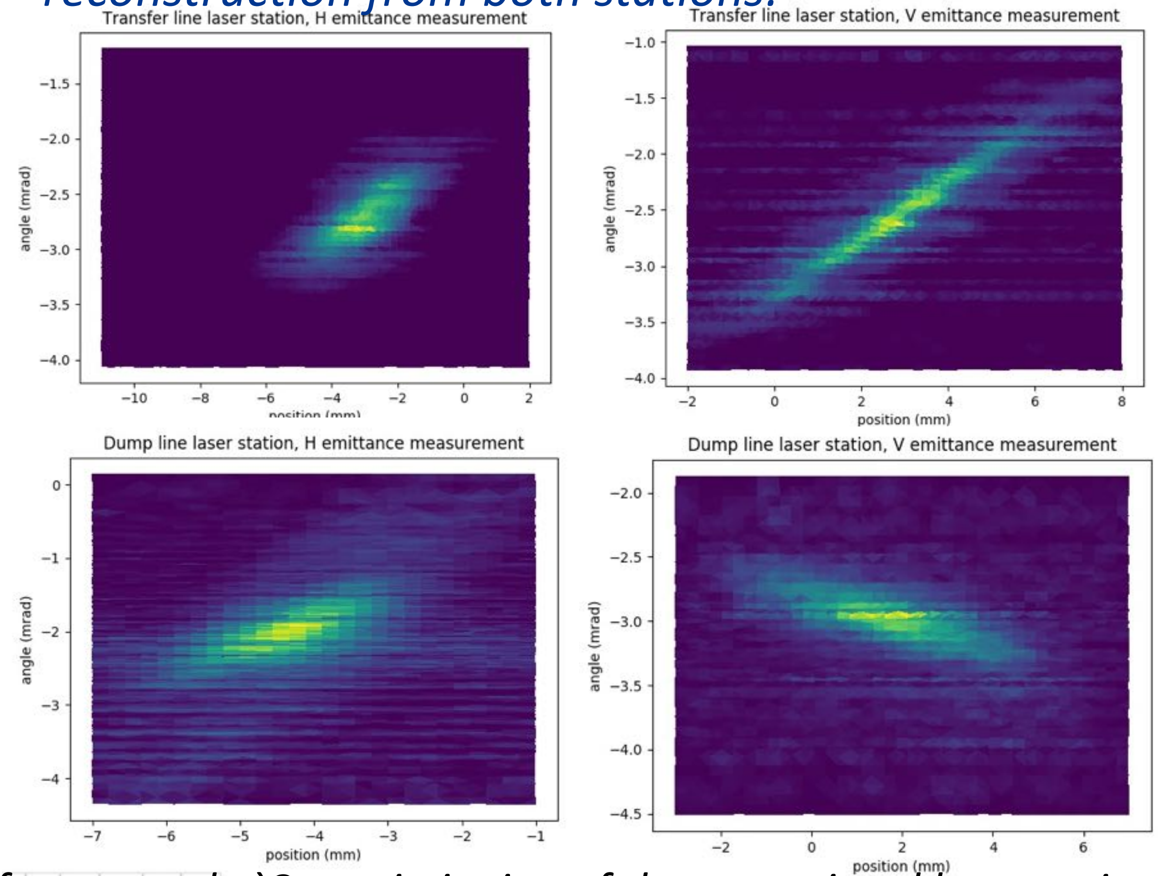




Linac4 dual laserwire results

T. Hofmann, G.E. Boorman, A. Bosco,
S.M. Gibson, A. Goldblatt, F. Roncarolo

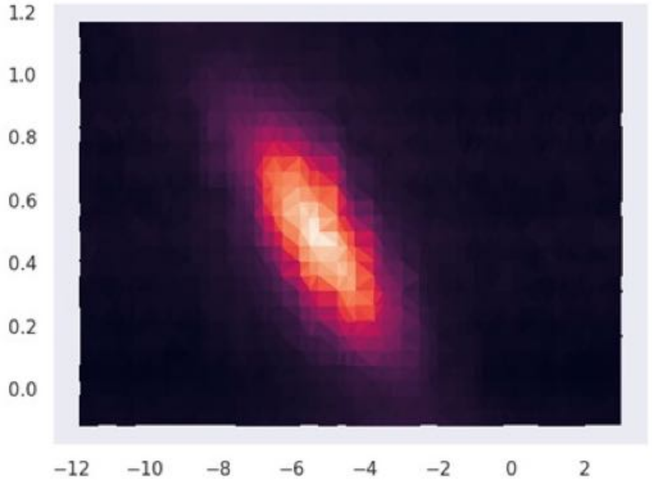
- ***Early commissioning data with all 4 diamond detectors:*** *horizontal and vertical emittance reconstruction from both stations:*



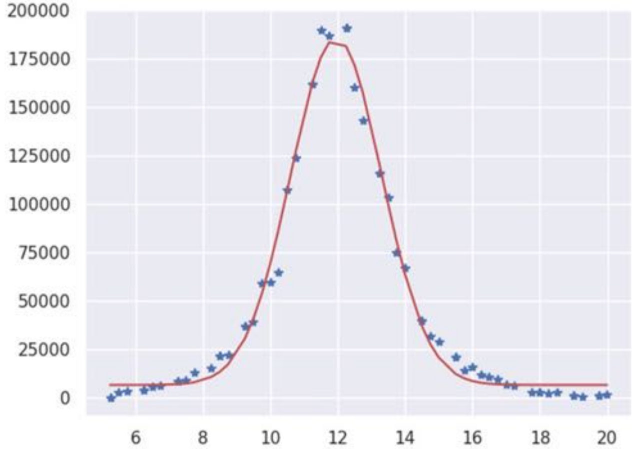
T. Hofmann et al , `Commissioning of the operational laser emittance monitors for Linac4 at CERN', WEPAL074, IPAC 2018.

- ***Operational data of Laserwire Emittance Monitor, from H plane Nov 2021:***

Phase Space measurement and emittance calculation from H0 meas.



Transv. Profile from H0 and electrons meas.



A. Goldblatt et al, IBIC2022

Gas-based beam diagnostics

- *Why not exploit the interaction of the particle beam with gas in the beam pipe?*
- *Non-destructive beam profile and position diagnostics have been developed based on three types of particle-gas interaction:*

Direct **ionisation** of residual gas	→	Beam Gas Ionization Profile Monitor
Fluorescence of injected supersonic gas-jet	→	Beam Gas Curtain / gas-jet
Inelastic interactions with gas target	→	Beam Gas Vertex monitor

PS Beam Gas Ionization (PS-BGI) Profile Monitor

S. Levasseur,
J. Storey et al

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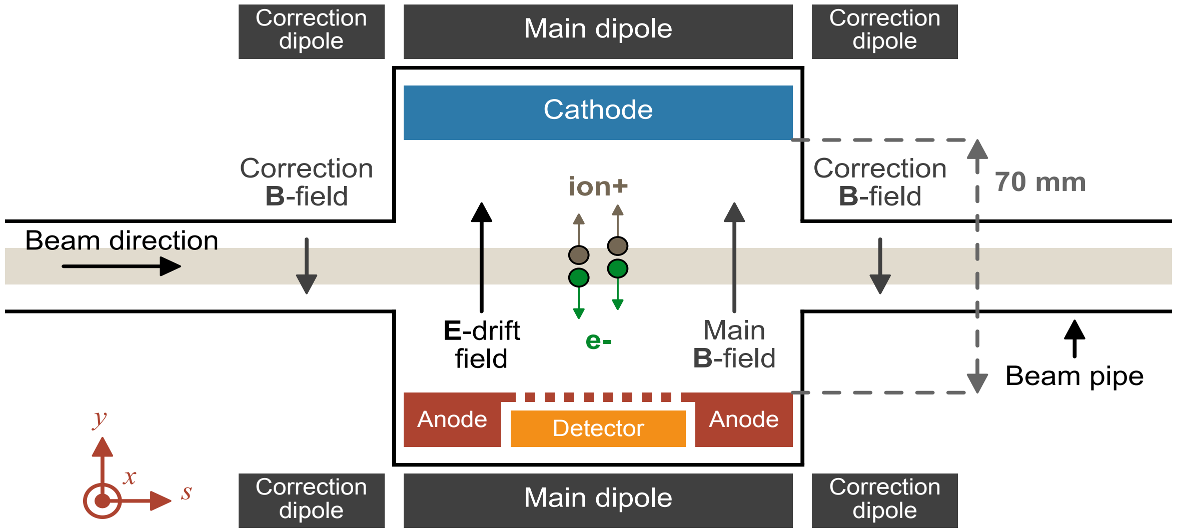
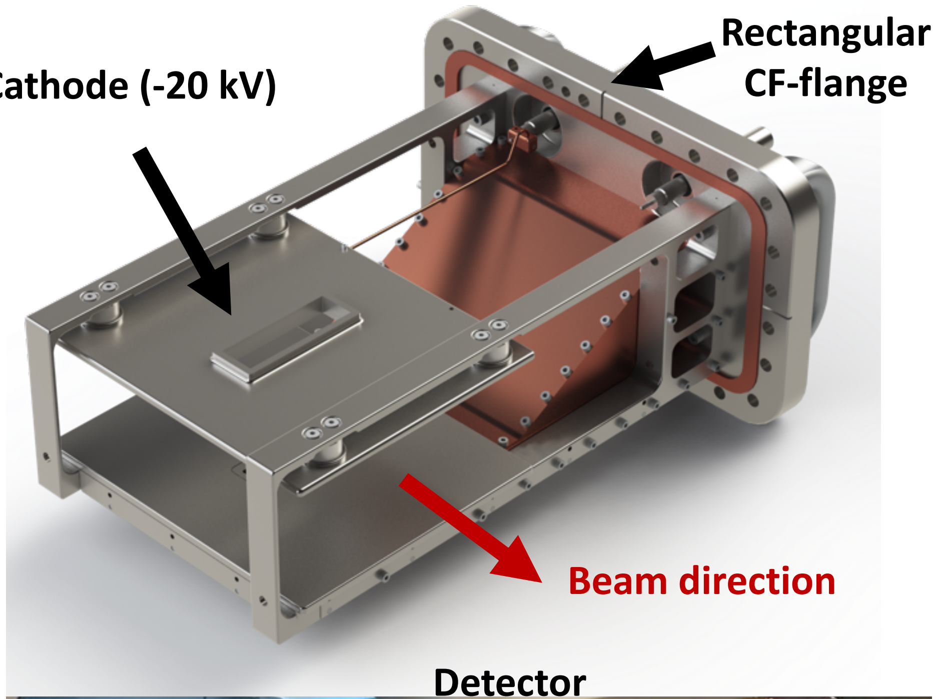
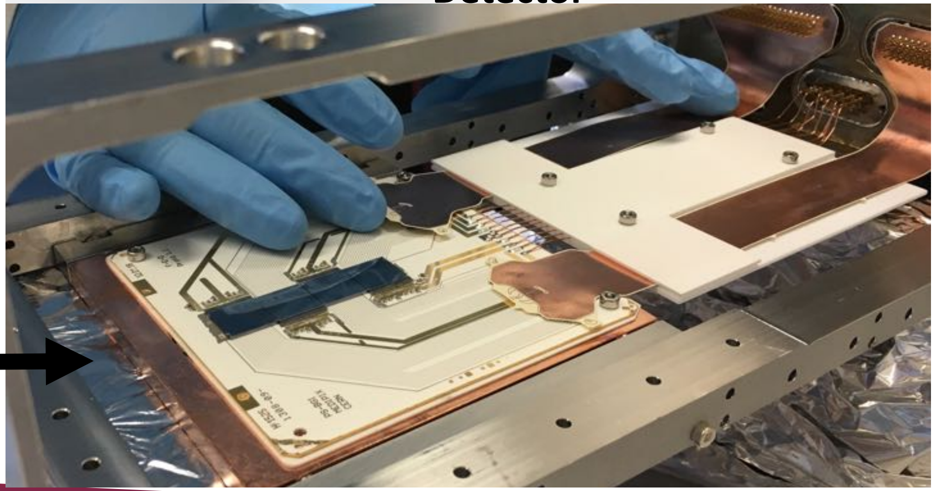
Purpose:
- Measure the transverse beam profile to improve the quality of the beam used for the LHC
- Integrated *non-destructive* beam profile throughout the cycle @ 1 kHz

Operating environment:
- Ultra-high vacuum: outgassing ≤ $1 \cdot 10^{-7}$ mbar·l·s^{-1}
- Radiation: 10 kGy/year at beam pipe, 1 kGy/year at 40 cm
- Presence of beam with losses and electro-magnetic interference





Detector



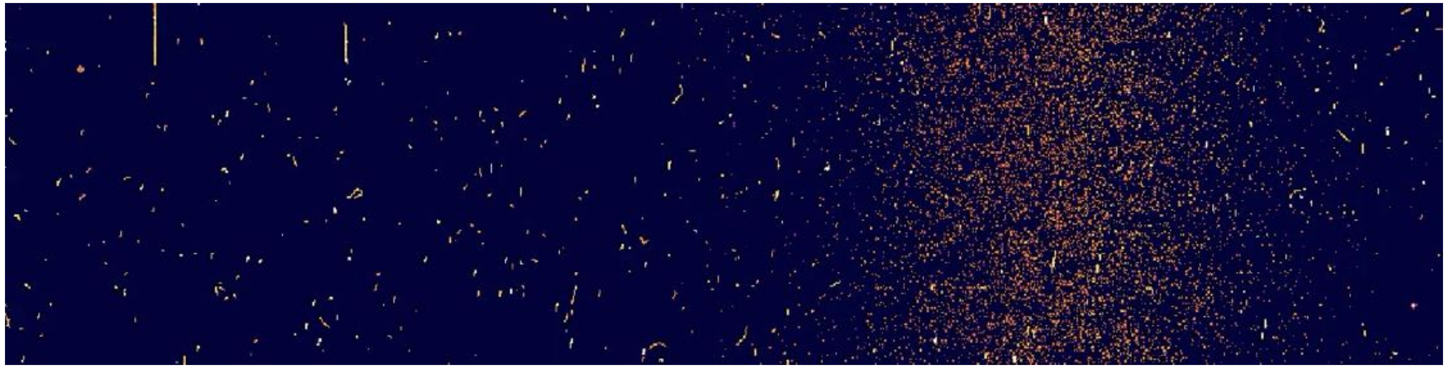
Specifics for the PS-BGI:
- Imaging of 10 keV ionization electrons using **hybrid pixel detectors**
- 285 kV/m electric field, 0.2 Tesla magnetic field

PS-BGI: turn-by-turn measurements of single bunch

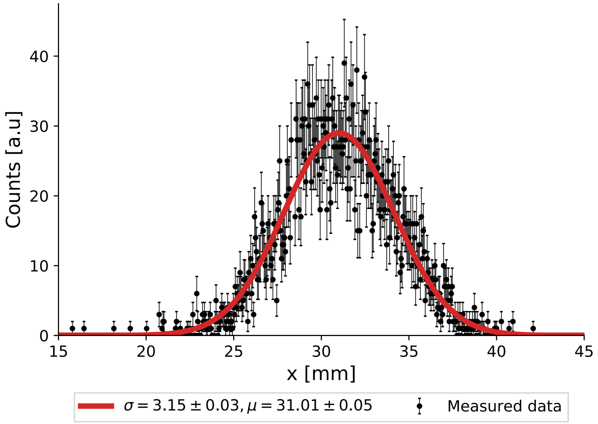
S. Levasseur,
J. Storey et al

- *BGI-Timepix3 allows, for the first time, continuous non-destructive turn-by-turn measurement of the transverse beam profile and position of single bunches.*

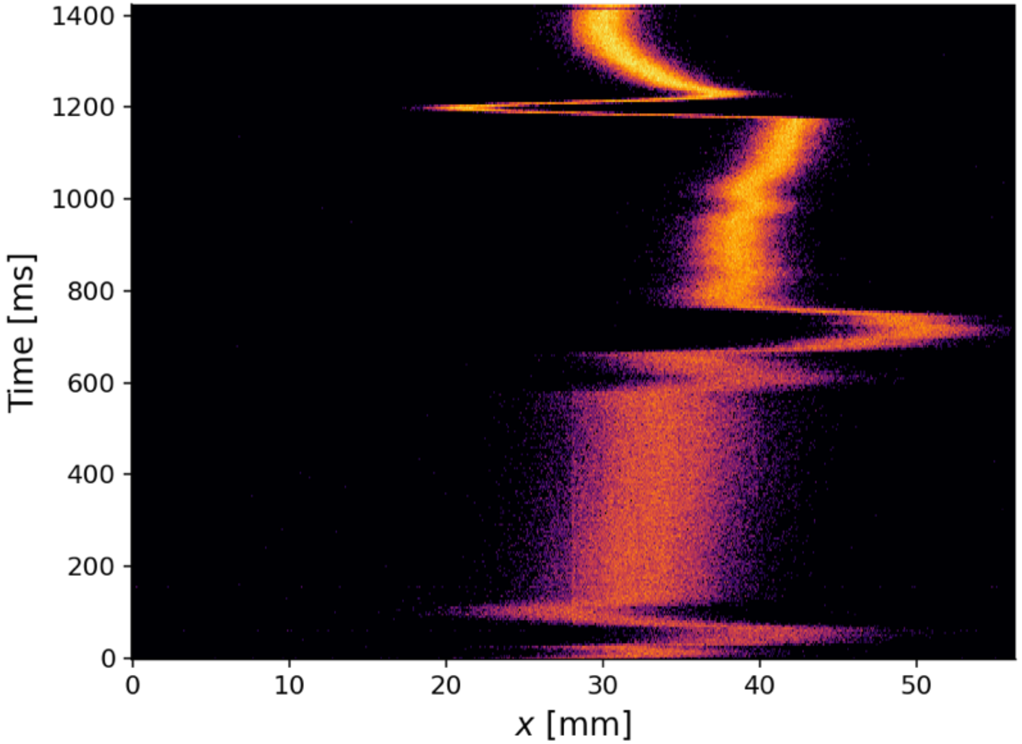
Measurement during injection, acceleration and extraction of particles in the PS



- *Slowed for viewing; 1.5s in real time*
- *Each images corresponds to a signal integrated over 10 ms*
- *Unfiltered data show background noise from beam loss.*



Profile and position
measured during a PS cycle



PS-BGI monitors now installed in both planes

S. Levasseur,
J. Storey et al

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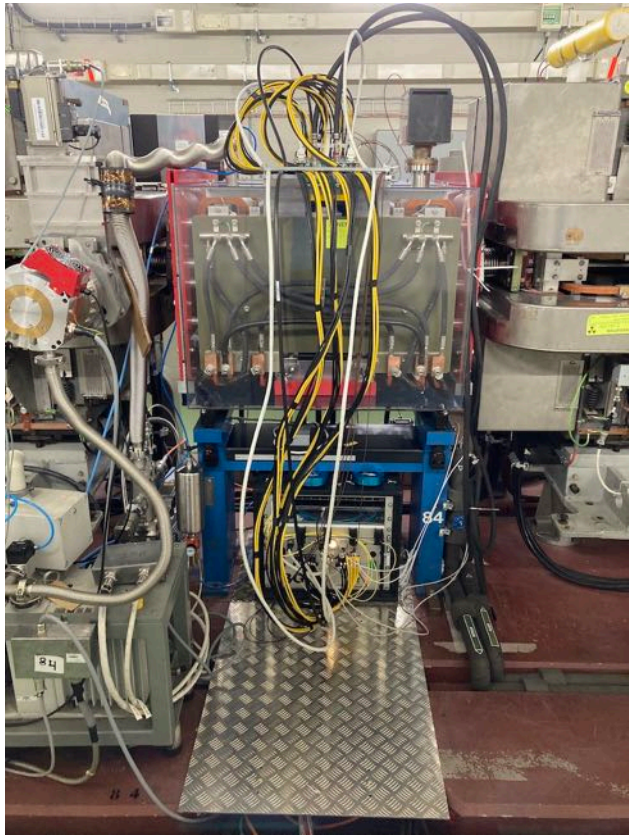
Horizontal BGI @ PS SS82

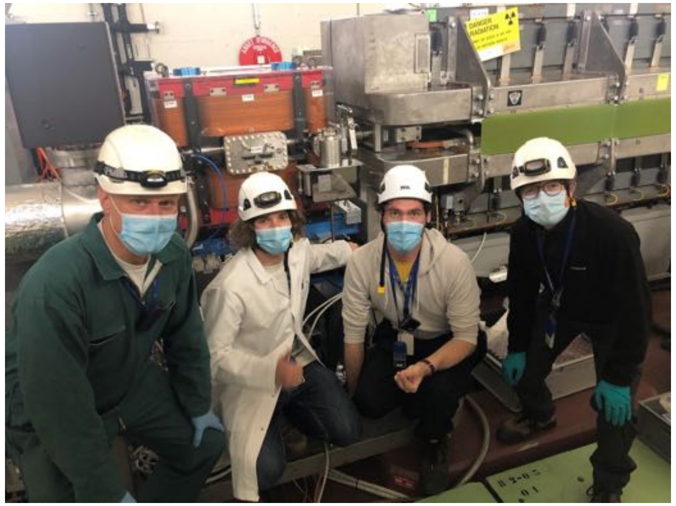
Vertical BGI @ PS SS84



Operational Beam Gas Ionisation (BGI) beam profile monitors installed in the PS.

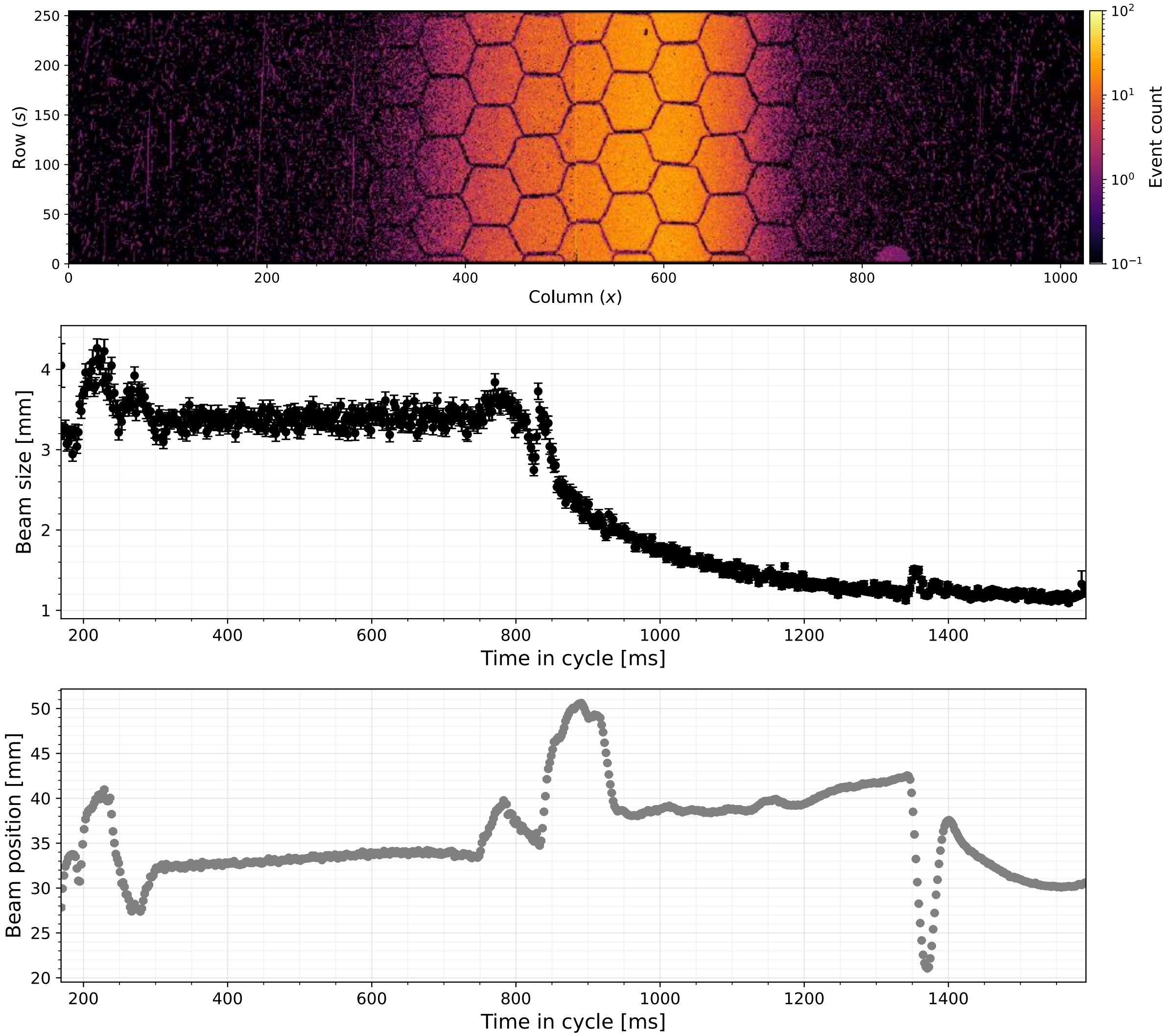
Based on the direct detection of rest-gas ionisation electrons with a Timepix3 hybrid pixel detector inside the beam pipe.

Culmination of 5 years of R&D.



PS-BGI: turn-by-turn measurements of single bunch

S. Levasseur,
J. Storey et al



Single bunch recorded on the first week of beam commissioning.

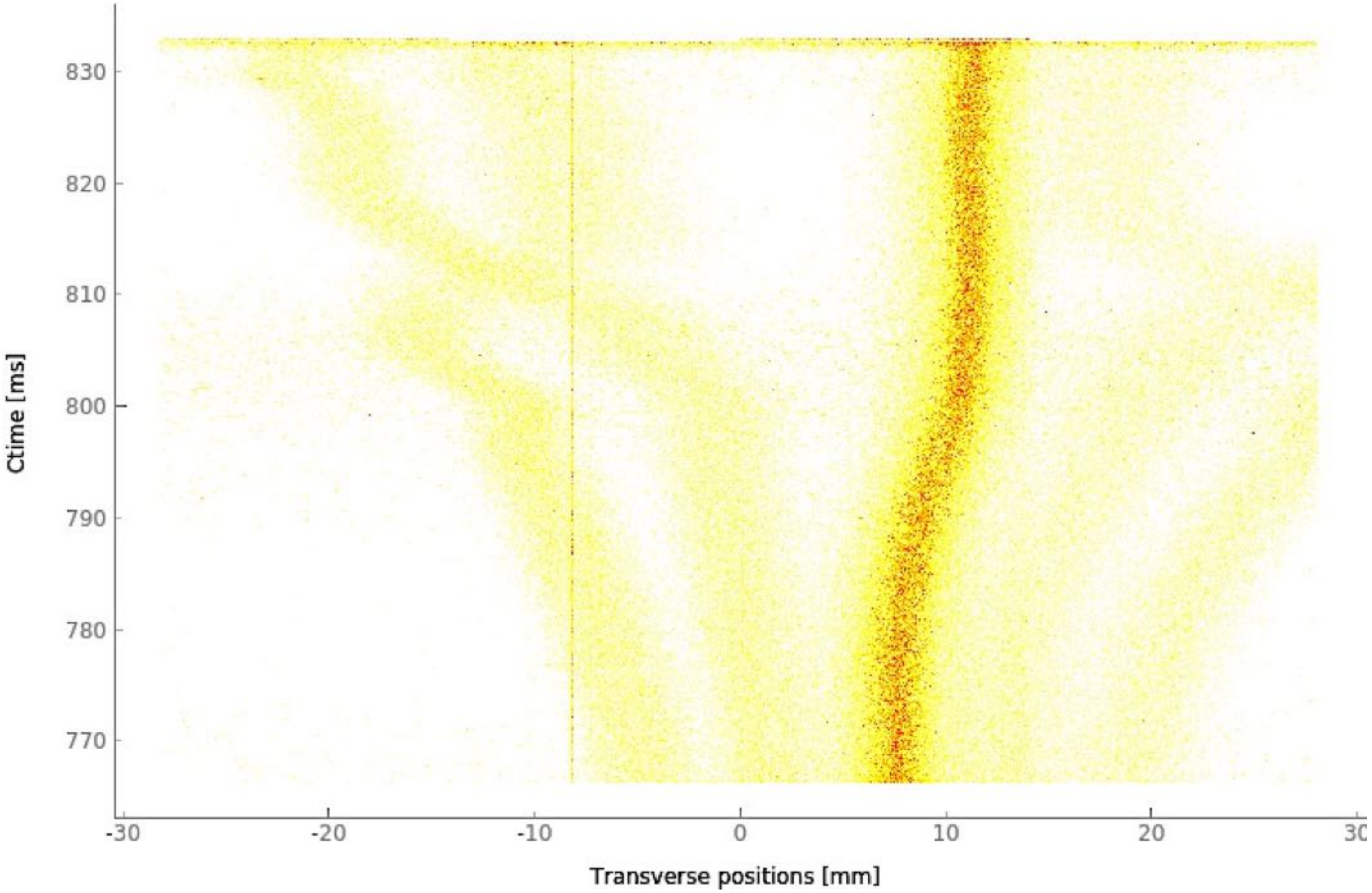
Beam size & position measured continuous throughout the full 1.2s cycle.

Measure up to 1024 beam profiles per cycle.

100% non-destructive measurement based on the ionisation of residual gas by the beam.

PS-BGI: beam splitting in Multi-Turn Extraction

S. Levasseur,
J. Storey et al



Measurements taken by OP-PS team with GUI based on BIPXL FESA class.

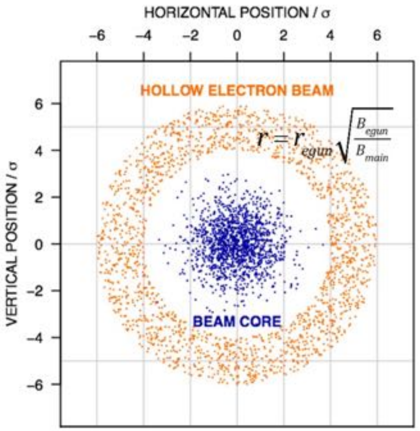
Multi-Turn Extraction (MTE) = beam is split into several beamlets in the transverse planes.

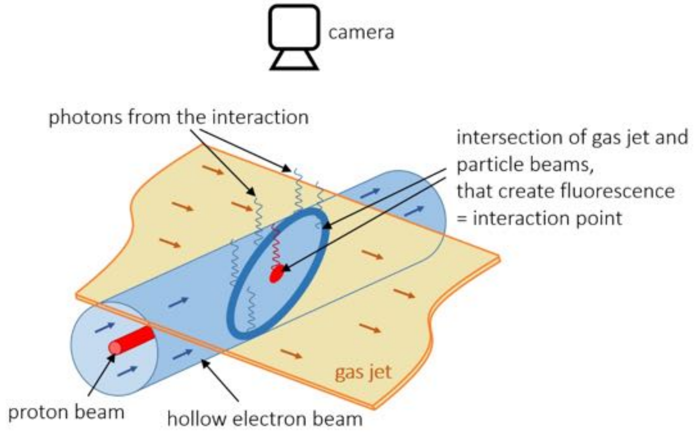
Continuous measurement with BGI shows the evolution of the beamlets throughout the cycle.

Allows to measure the beam size, position & relative intensity of each beamlet.

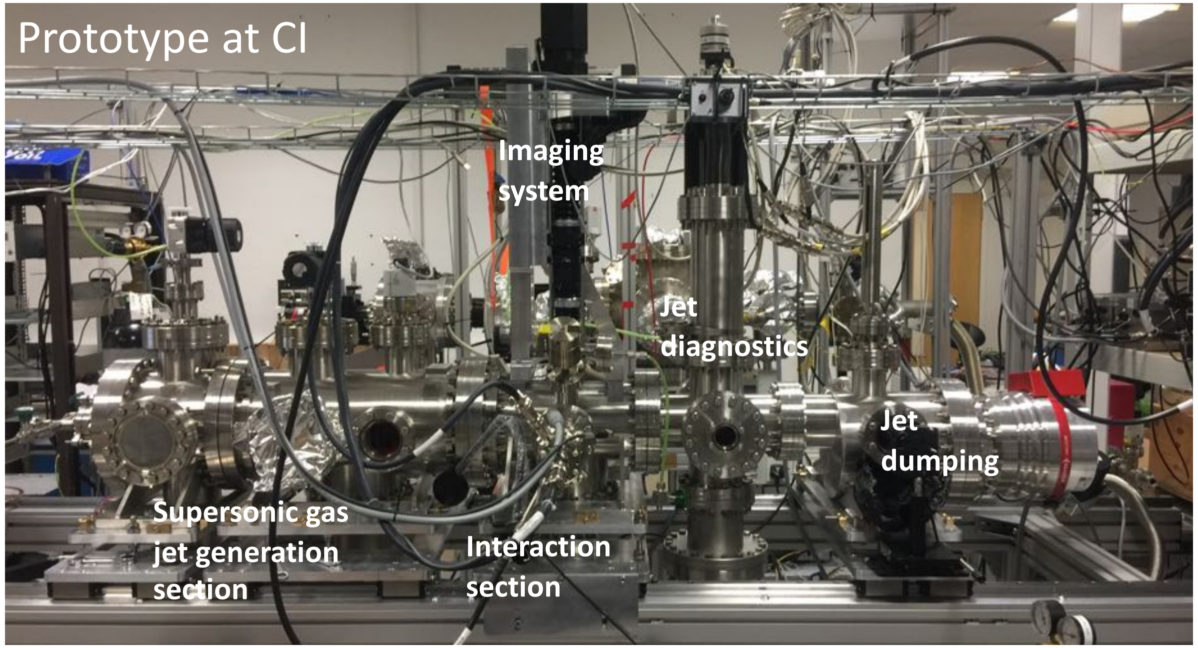
UNIVERSITY OF LIVERPOOL

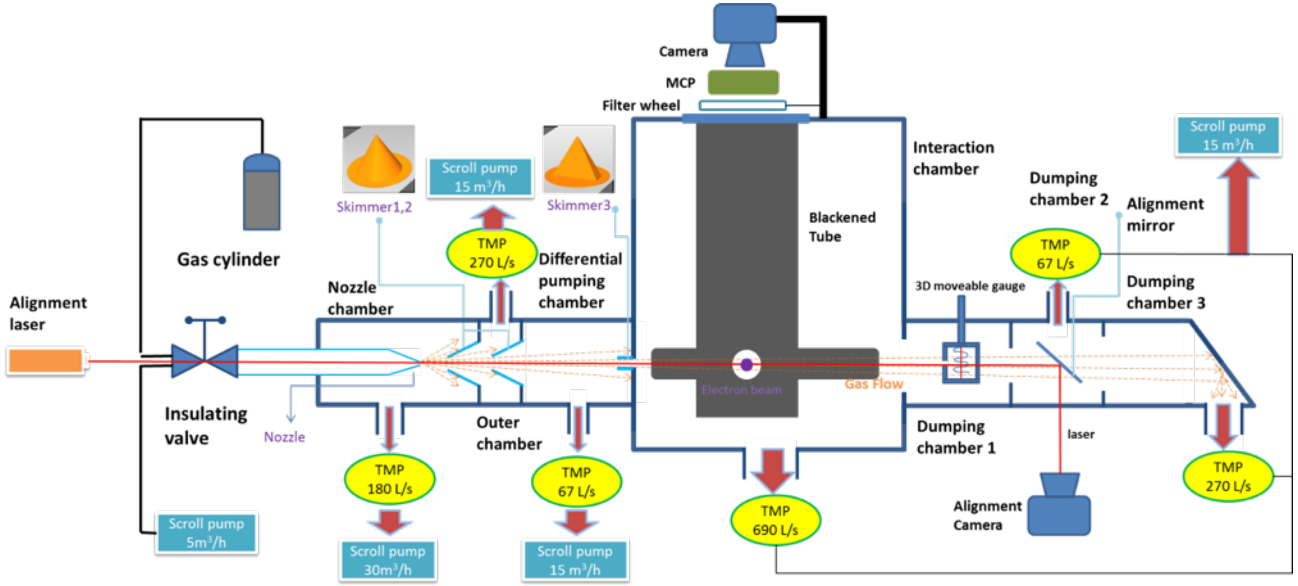
The Cockcroft Institute of Accelerator Science and Technology





- ***Aim:*** development of a non-invasive beam profile monitor for the hollow electron lens project.
- Beam interacts with gas-curtain formed by supersonic jet passing through the beam pipe.
- Prototypes developed at CI in collaboration with GSI and CERN.

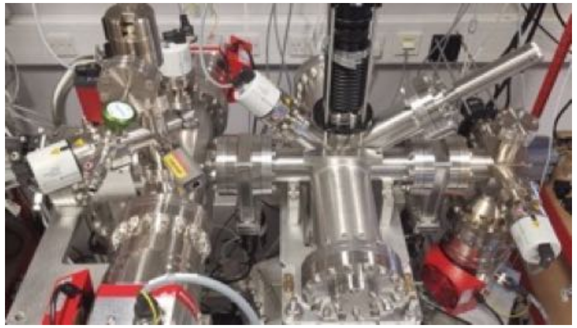


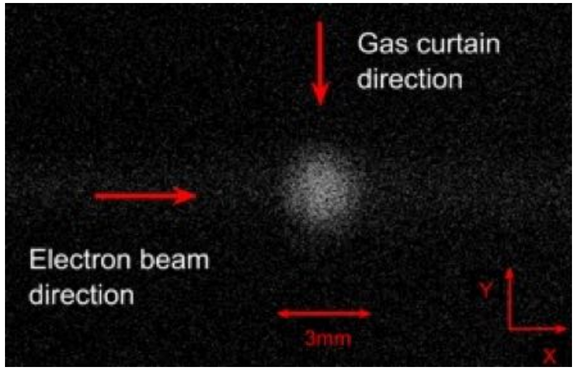


HL-LHC Beam Gas Curtain profile monitor

C. Welsch, H. Zhang, et al

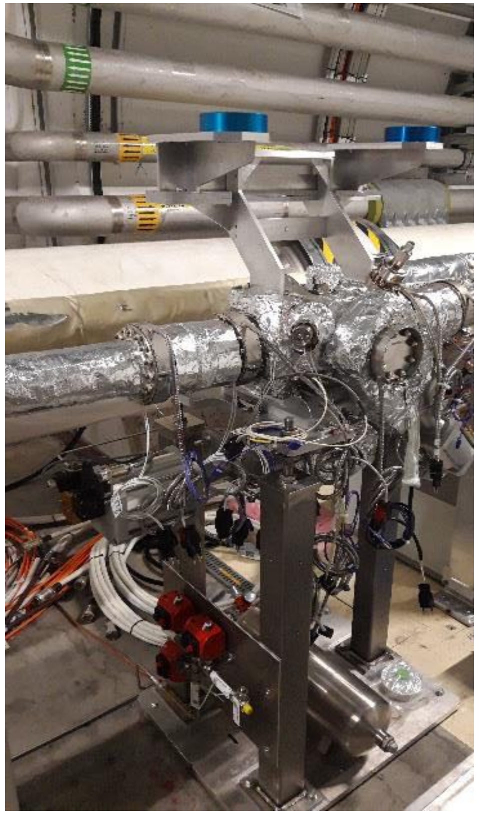
BGC @ CI/UK



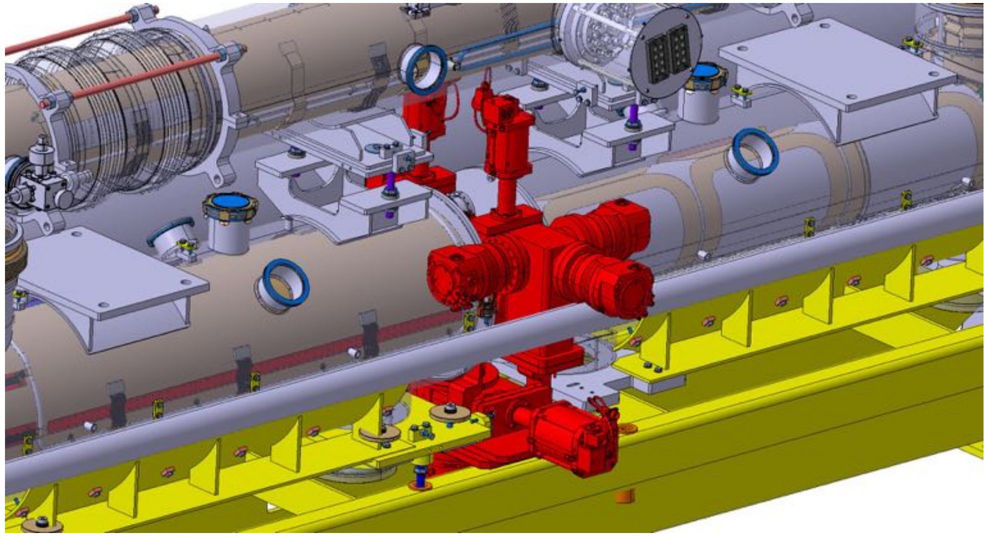


BGC @ HEL test stand in 2022

Beam induced fluorescence from a Supersonic gas curtain - e^-/p^+beam overlap monitor



Test of BGC @ LHC during run 3



Integration studies of the BGC into the Hollow e-lens

Please see Hao Zhang's BGC talk & poster by Oliver Stringer

HL-LHC Beam Gas Vertex Detector

H. Guerin & BGV team

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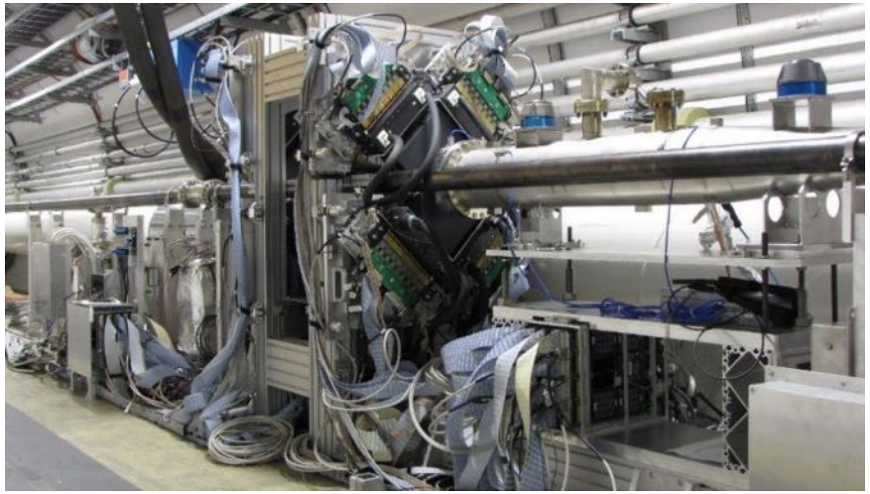
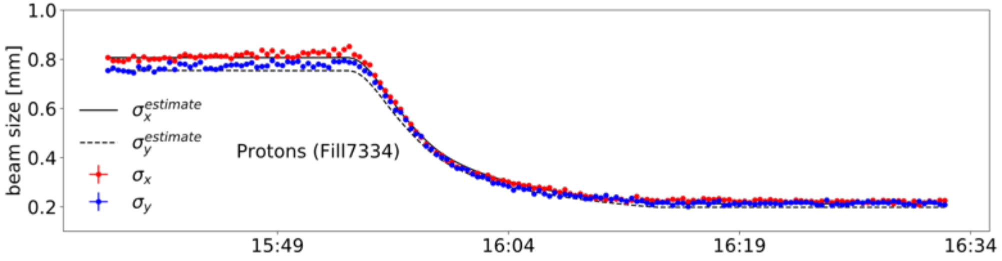
Prototype beam gas vertex detector *demonstrated on online beam size measurements, with resolution down to 3µm in Run II. Two tracking layers.*

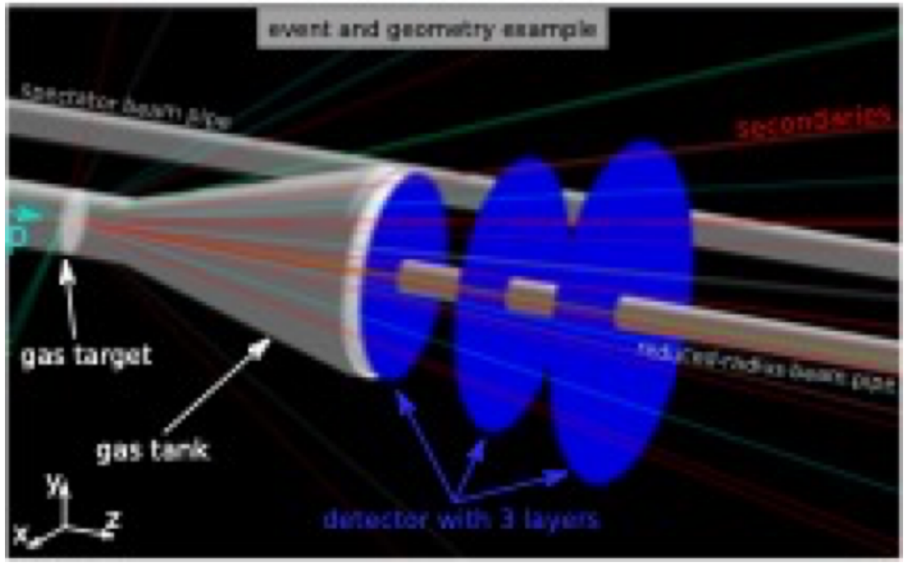




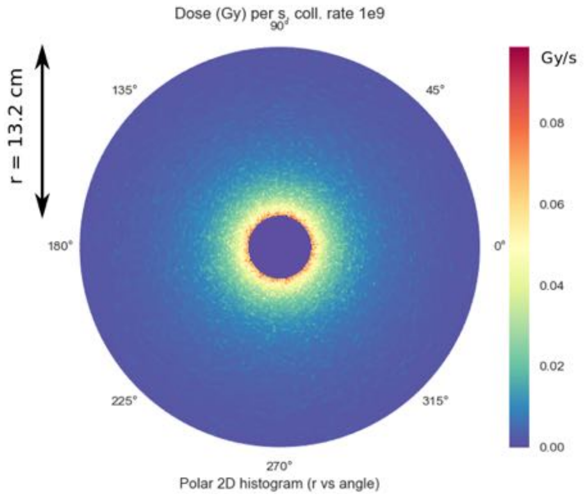
Courtesy, R. Jones

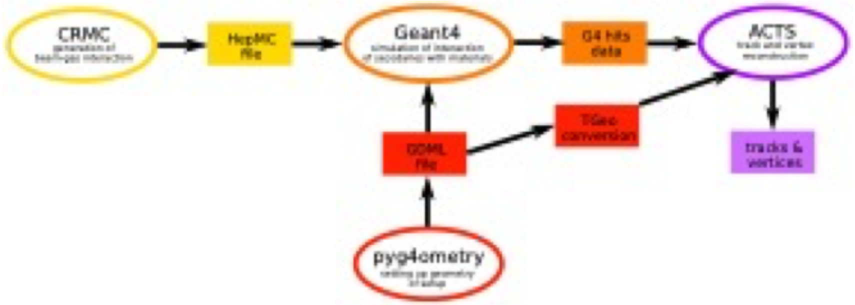
Hélène Guerin's studies of BGV:

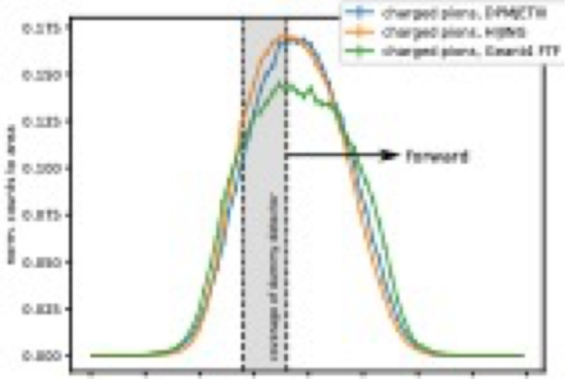
Geant4 simulations of design for HL-LHC with three layers, with geometry build using pyg4ometry (RHUL / BDSIM), gas-jet target.



Radiation dose





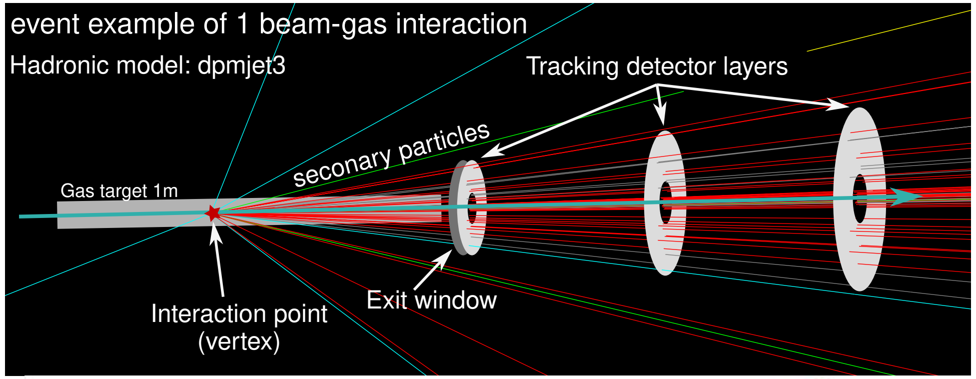


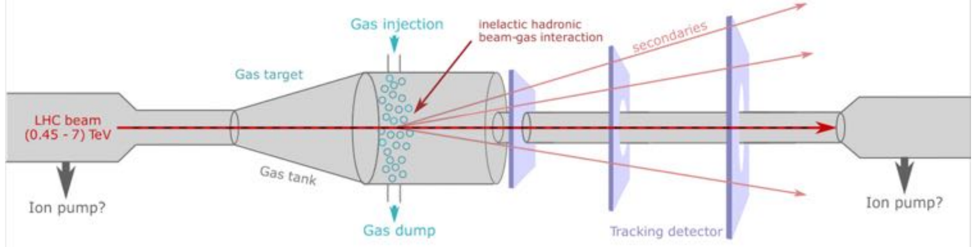
Progress on HL-LHC Beam Gas Vertex Detector

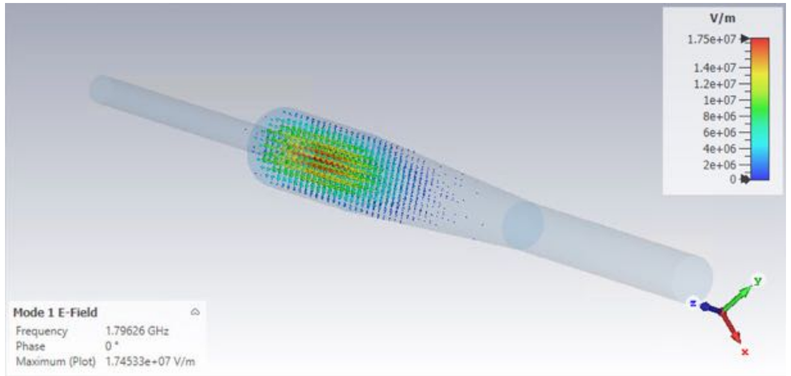
H. Guerin & BGV team

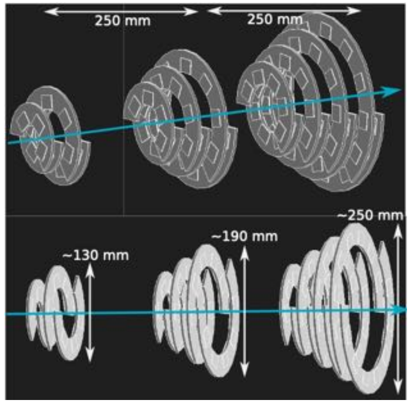
Simulated performance has no showstopper for a distributed gas target, although a gas-jet target would improve performance; results point towards a high resolution, compact tracker.

- ***Decision for TimePix4*** hybrid pixel detectors tracker (design and produced with Oxford: D. Hynds and R. Plackett).
- ***Tank design optimised*** to increase the tracker acceptance and reduce the tank impedance.
- Baseline is an ***upgraded distributed gas target***; a ***gas-jet target option*** is being assessed for performance and implementation requirements.
- Possible locations for the Beam 1 instrument identified, ***estimating radiation induced*** downstream by BGV operation.
- ***Event reconstruction***: work ongoing to unfold the beam profile from the distribution of reconstructed vertices.
- *Design review in October 2022.*





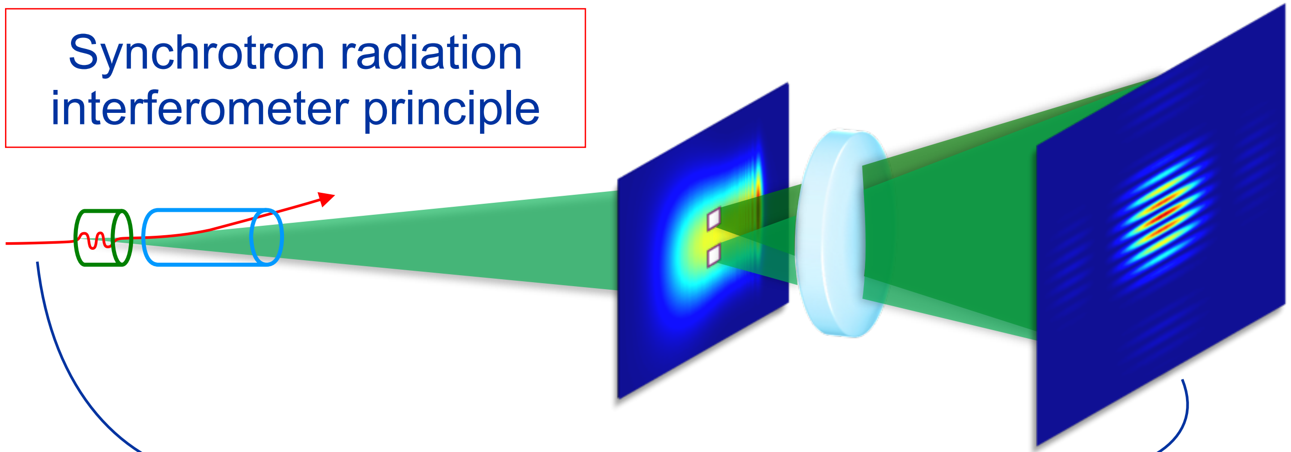




HL-LHC Synchrotron Radiation Monitor

D. Butti & CERN BI

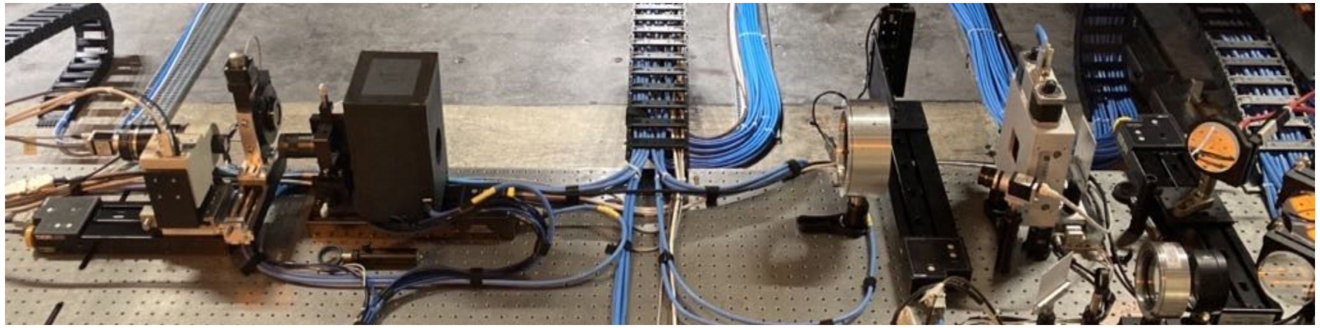
Synchrotron radiation interferometer principle



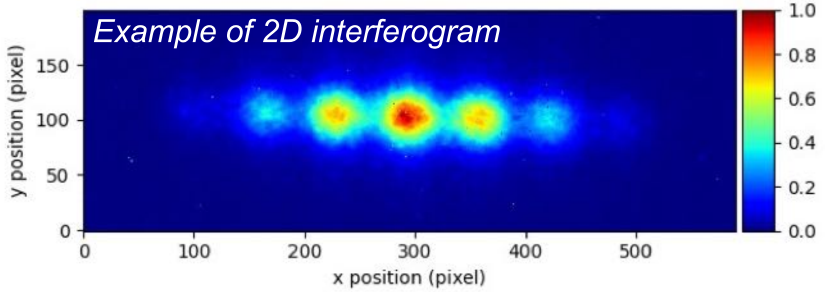
source size ↔ interferogram visibility

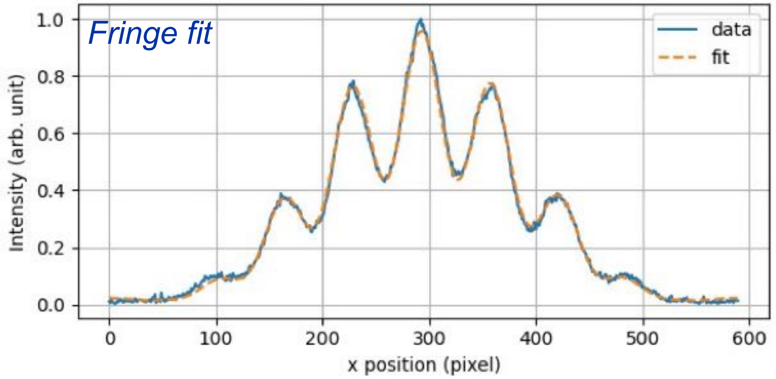
Goal: provide an absolute and non invasive transverse size measurement for HL-LHC

Instrument refurbished and ready for LHC Run 3

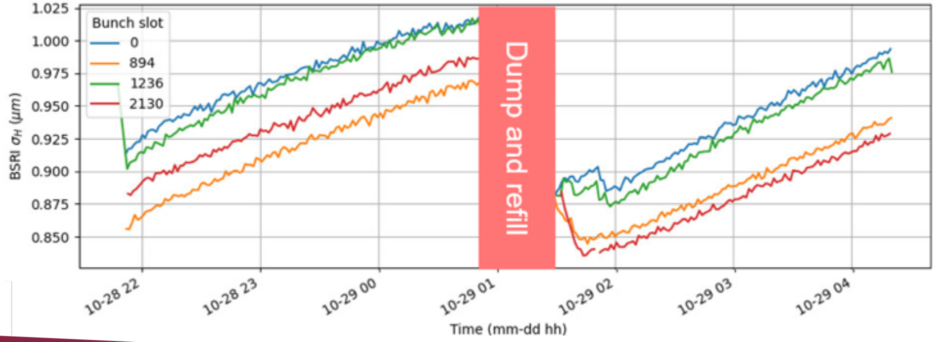


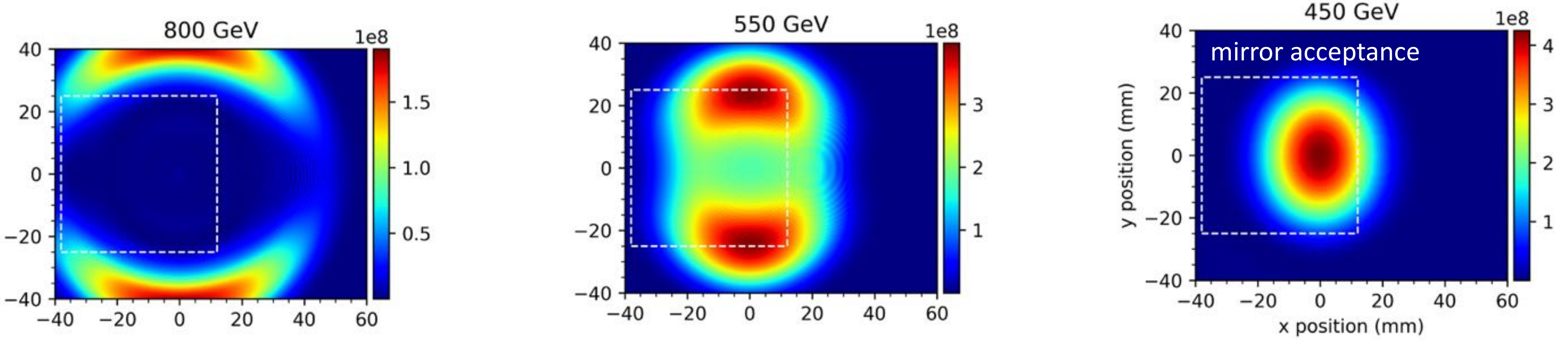
First measurements from October 2021 beam test



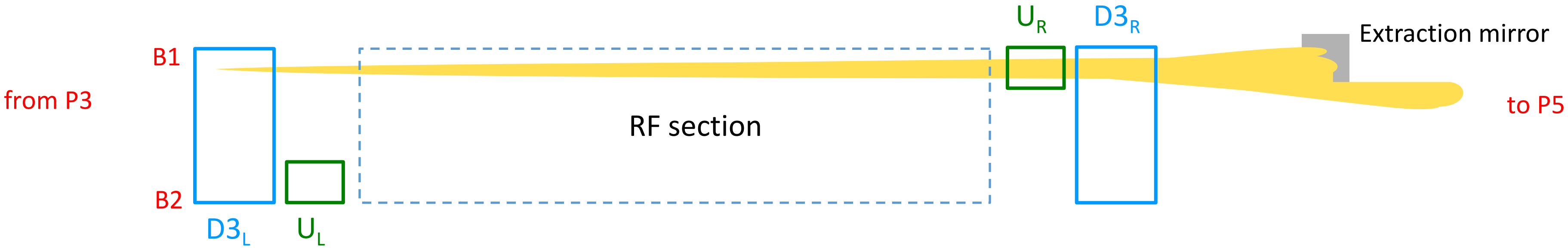


Real-time monitoring of transverse size during two fills

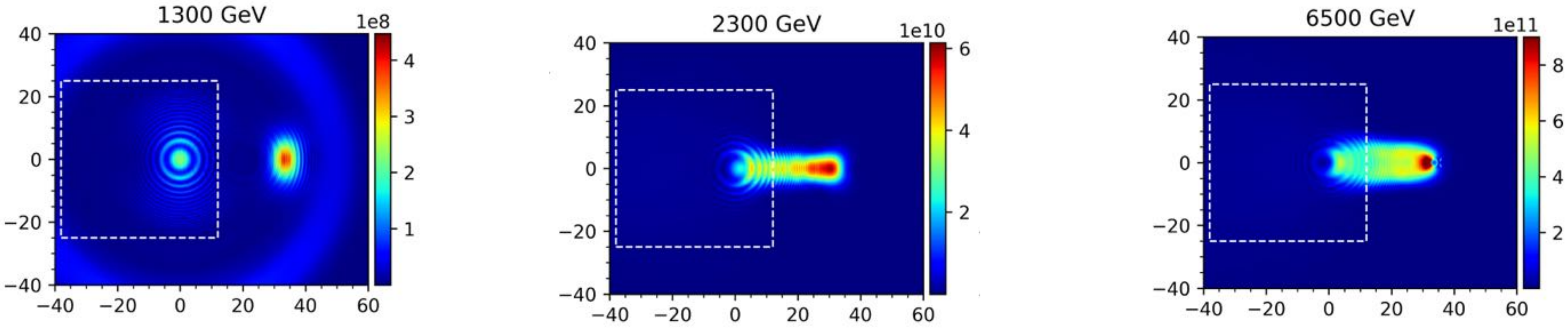




Undulator radiation



Edge radiation



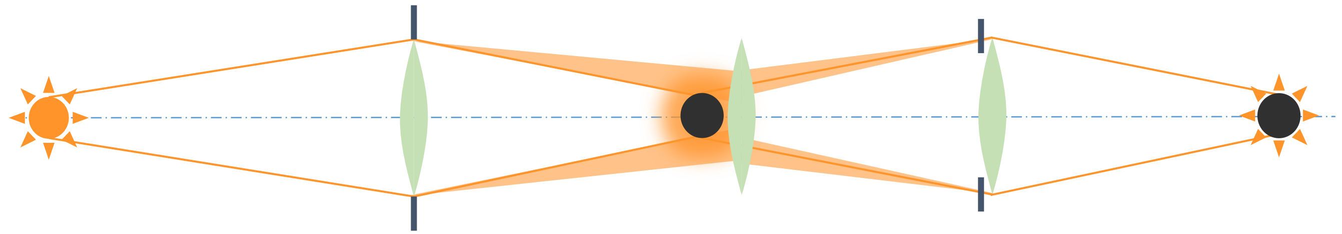
D3 Core radiation

HL-LHC SR Halo Monitor

D. Butti & CERN BI

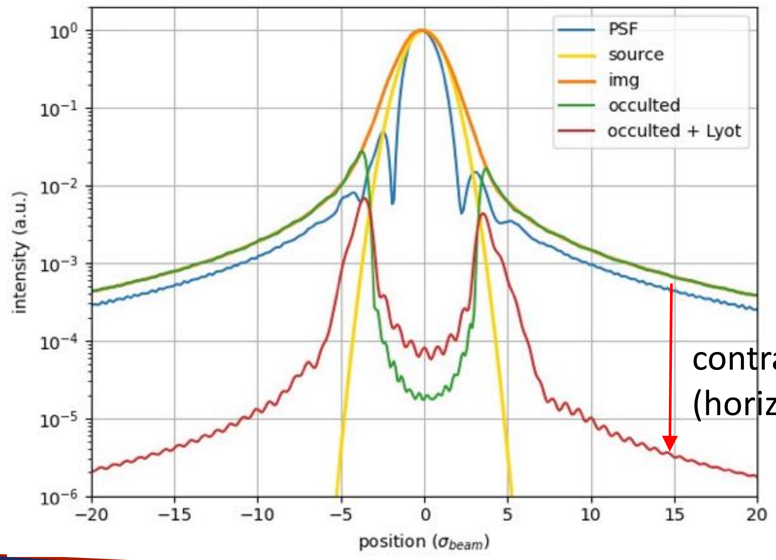
Coronagraph principle

Achieve high-contrast imaging by suppressing diffraction background



Propagation of diffraction: "created" by aperture → refocused by field lens → scraped by Lyot stop → image w/o diffraction halo

Goal: measure the halo population of HL-LHC beams

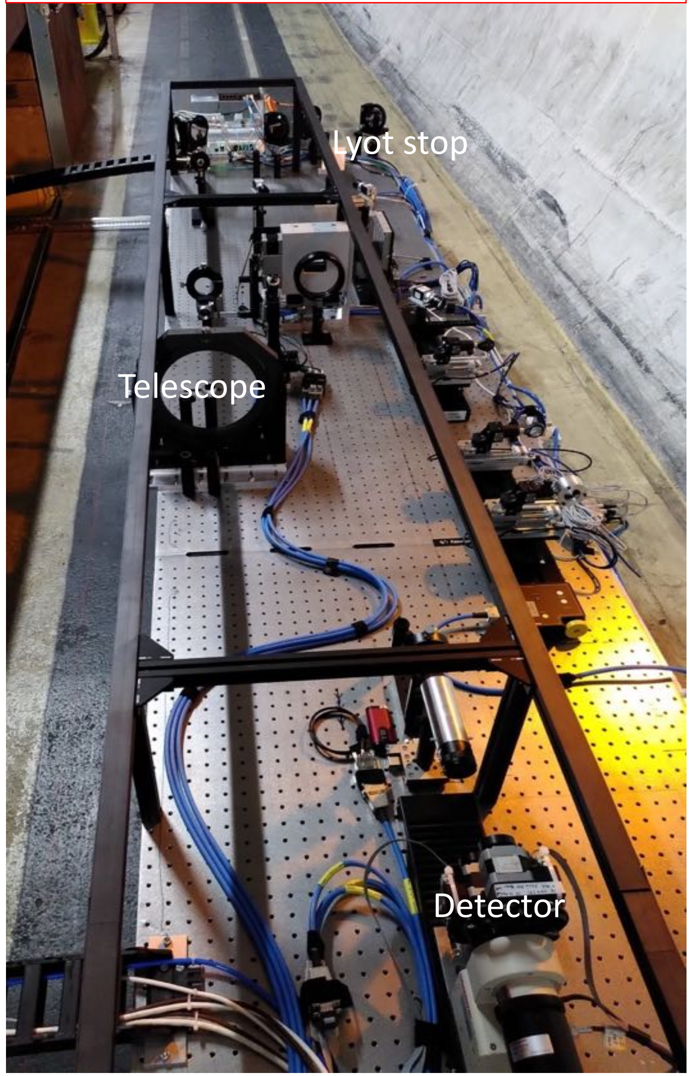


contrast gain in diffraction background (horizontal direction only)

Simulations

Applicability of coronagraph to synchrotron radiation not trivial:
→ extensive simulations

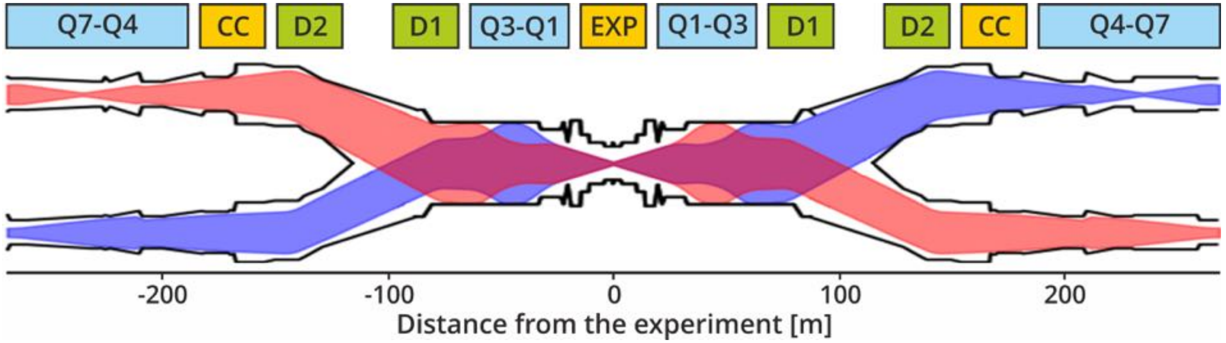
Test setup installed in LHC to benchmark simulations

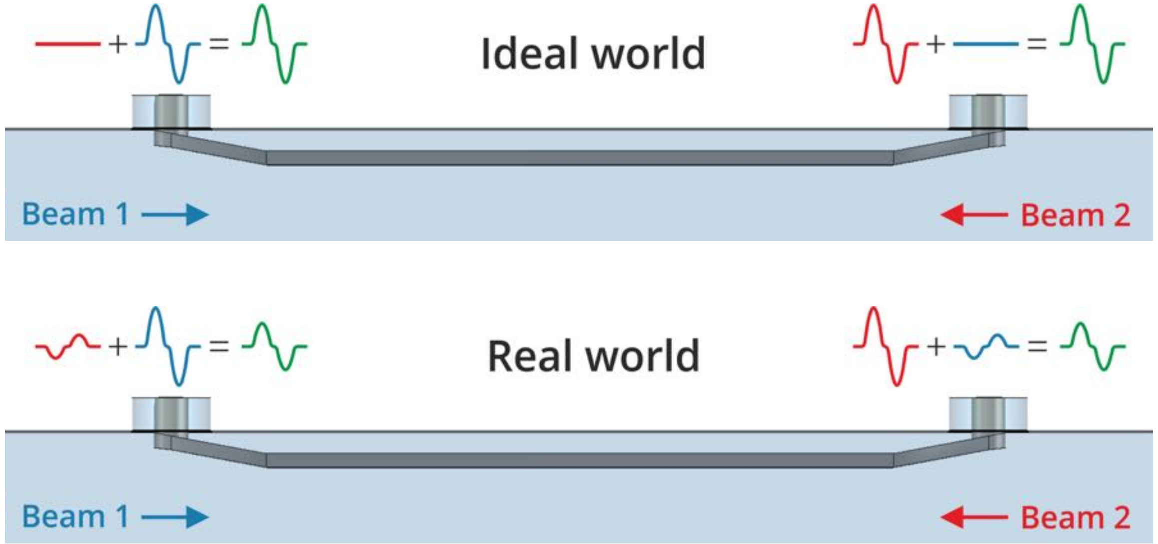


Fast Beam Position Monitors

HL-LHC Interaction Region BPMs

Doug Bett, Irene Degl'Innocenti,
Phil Burrows et al



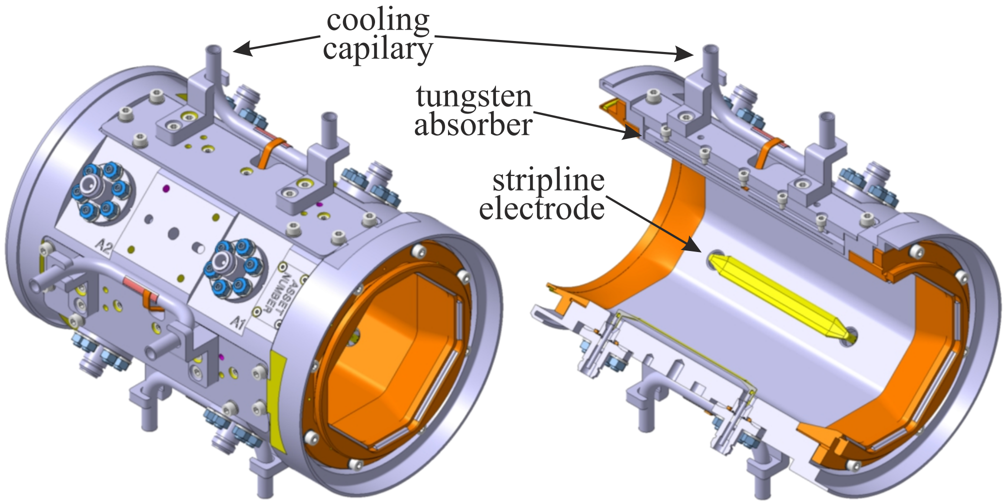


- *Near the interaction region, both counter-propagating beams coexist within a single pipe.*
- *The position of each beam can be measured by use of stripline pick-ups that are highly directional, so the main signal from each beam can be distinguished at each port.*
- *In practice, the signal observed on each output port is a combination of both beams, and the distortion must be accounted for to obtain accurate measurements.*
- ➢ *Requires fast digital processing*

HL-LHC Interaction Region BPMs

Doug Bett, Irene Degl'Innocenti,
Phil Burrows et al

UNIVERSITY OF OXFORD



- *24 new stripline BPMs will be installed at IR1/5.*
- *RFSoC device combines FPGA-style programable logic with a CPU and RF-ADCs will be used for direct digitisation.*

See IBIC 2020 & 2021 proceedings:
https://doi.org/10.18429/JACoW-IBIC2020-WEPP12
https://doi.org/10.18429/JACoW-IBIC2021-MOPP24

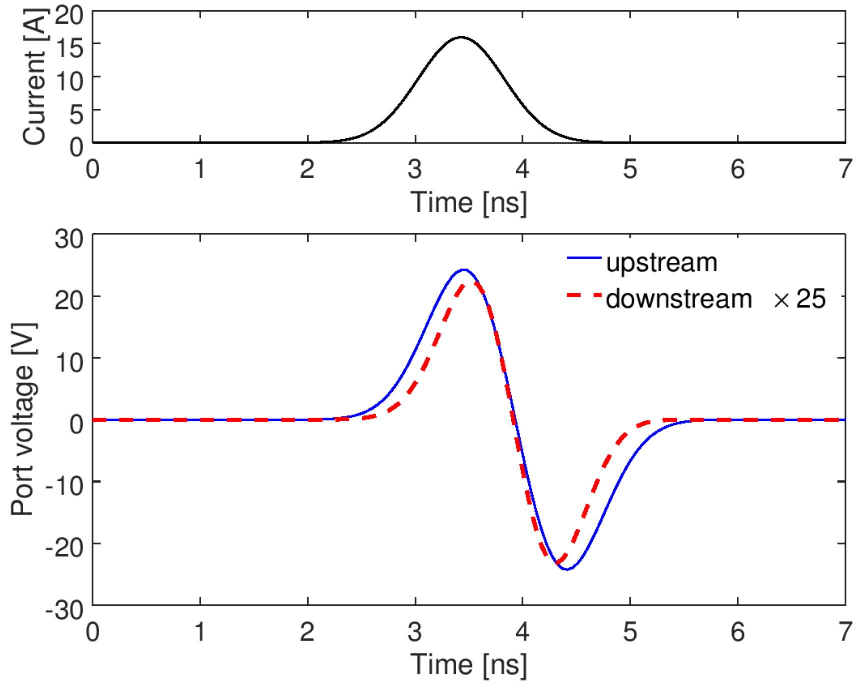


Figure 3: Input beam current profile (top) and voltage induced at the upstream end (solid) and the downstream end (dashed and magnified x25).

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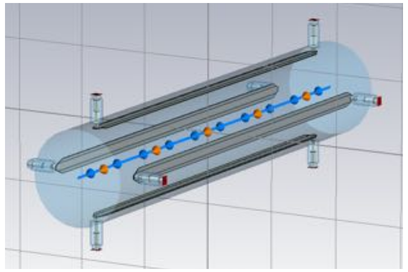
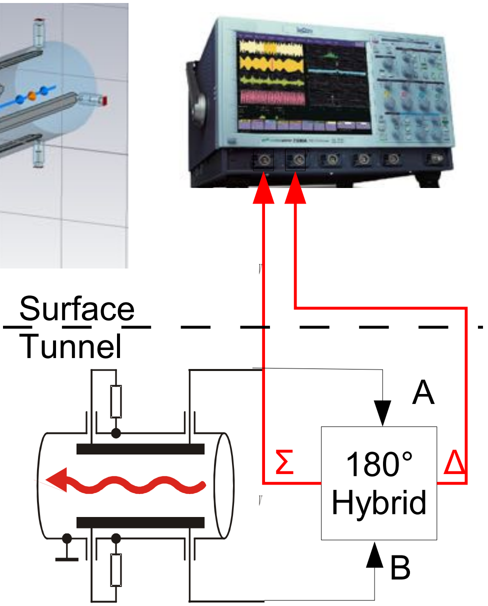
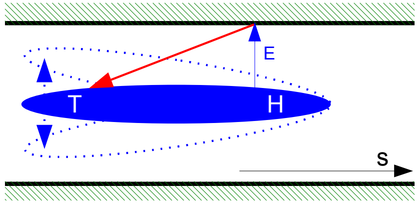
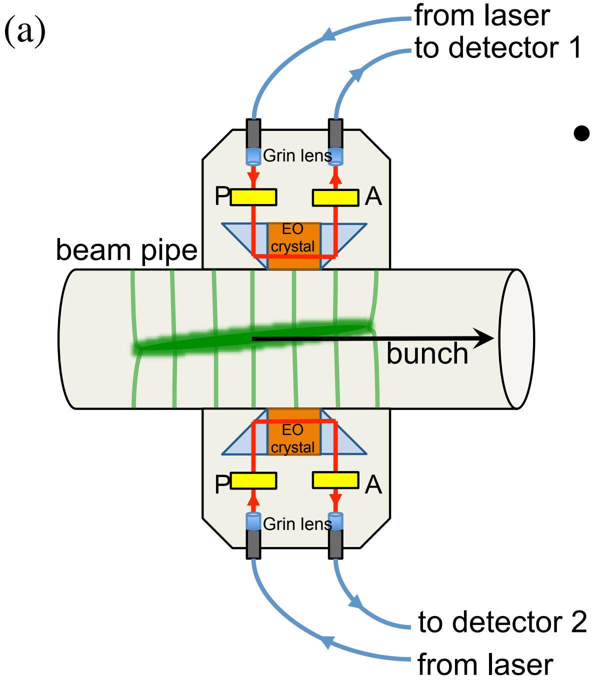
Bandwidth of conventional diagnostics is typically **limited** to a few GHz by the pick-ups, hybrid, cables and acquisition system.

- ➢ replace capacitive pick-ups with fast electro-optic crystals
- ➢ replace electric cables by optical-fibre readout









- ***Electro-Optic BPM principle:***
  - Monitor the polarisation of light in birefringent crystals in response to the electric-field of a passing bunch
    - Transverse position along passing bunch is measured
    - A fibre coupled laser source and photodetector read-out are housed away from the accelerator tunnel.
    - As polarised light passes through the crystal, the electric field of the bunch induces a change in polarisation state by the linear Pockels effect.

High-bandwidth EO-BPM development for HL-LHC

A. Arteche,
S. Gibson et al

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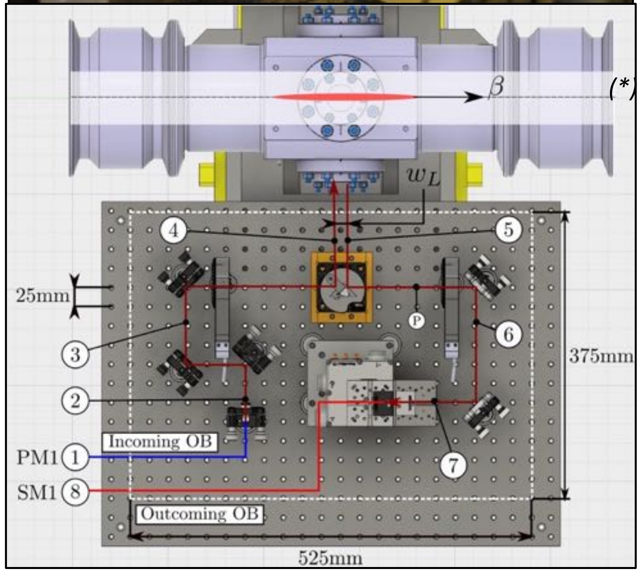
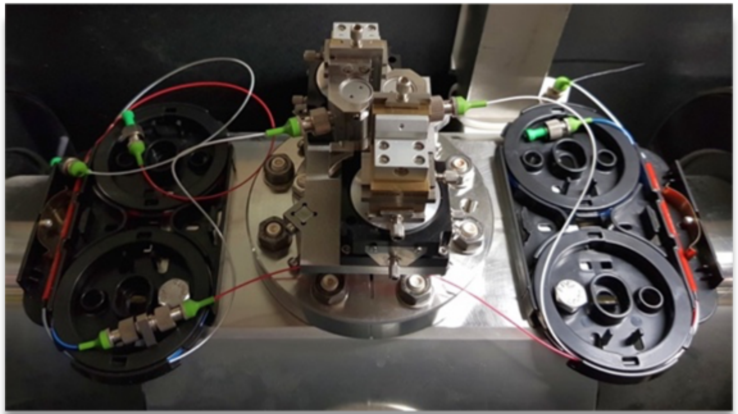
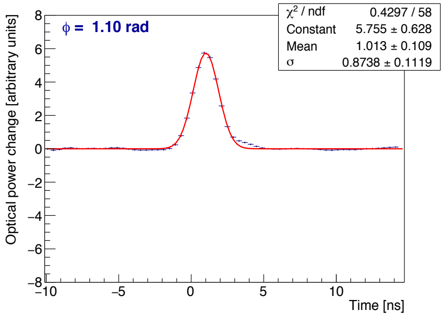
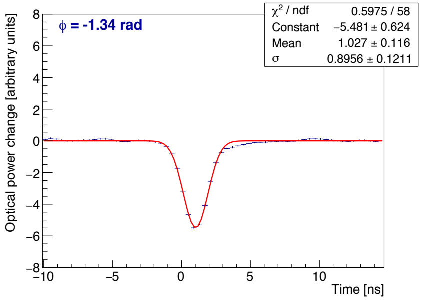
SPS Prototype → Miniaturisation → HL-LHC compatible waveguide design

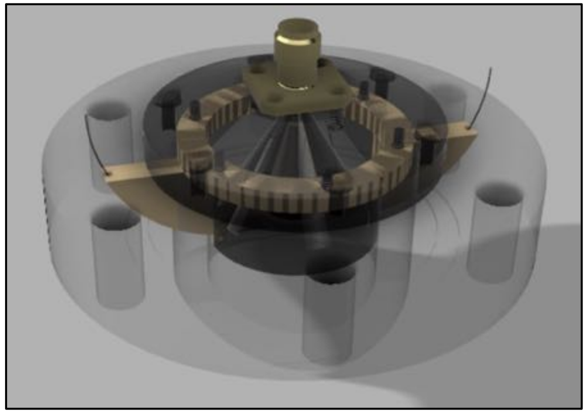


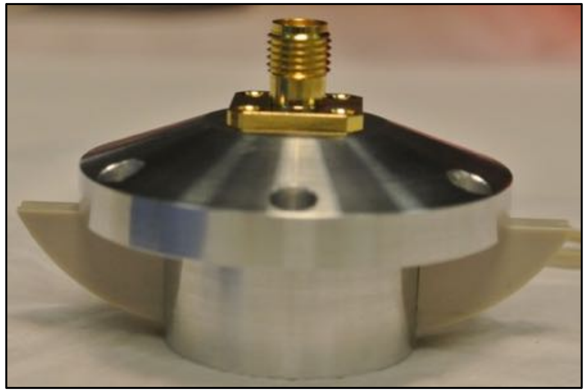






- Bulky side boxes replaced by more compact fibre-optic design and finally became totally fibre-coupled for the waveguide design.

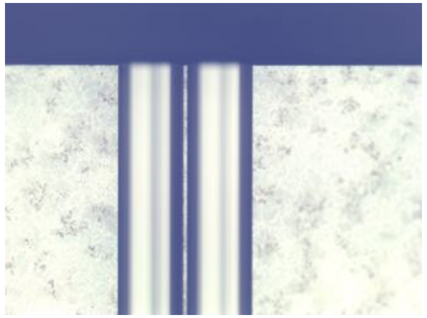




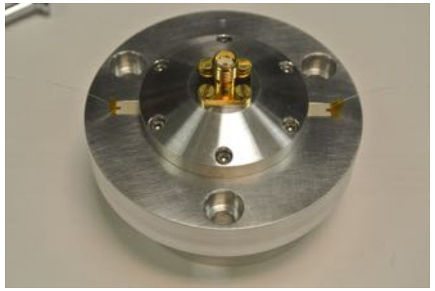
New EO waveguide design shipped to CERN for beam tests

A. Arteche,
S. Gibson et al

- EM simulations of pick-up performed in CST to optimise field strength at waveguide.
- Partnered with UK industry to produce waveguides suitable for our custom design:

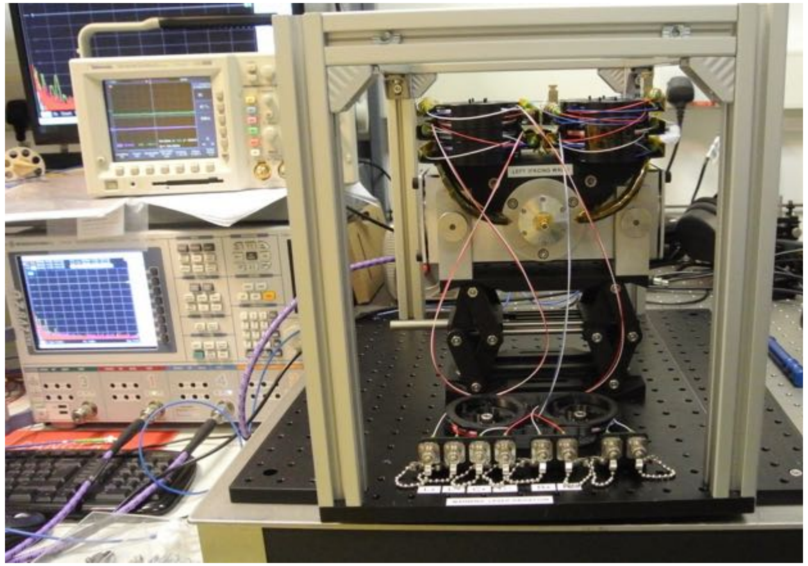


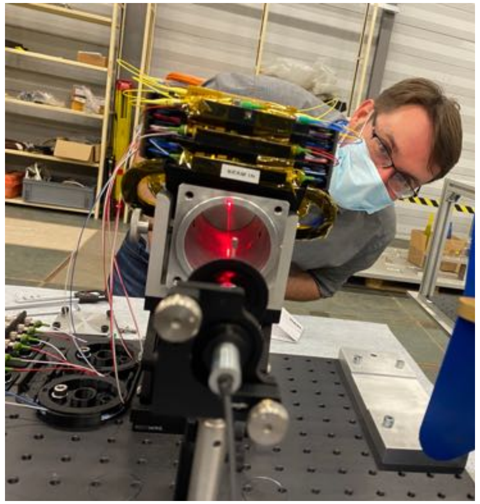
Optical inspection of waveguide in RHUL clean room

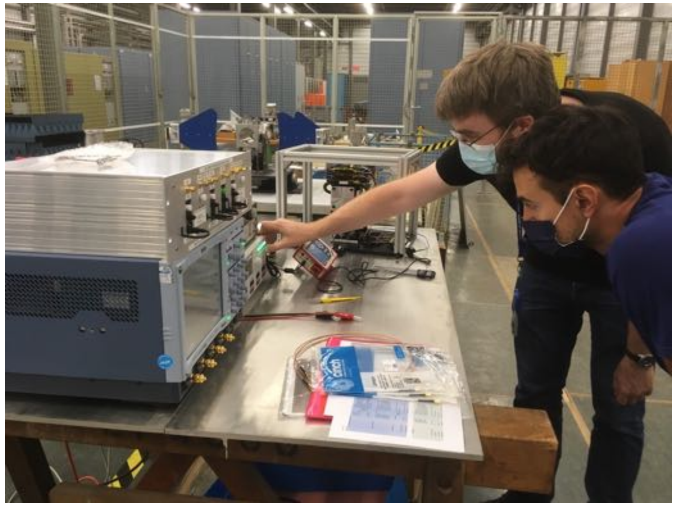


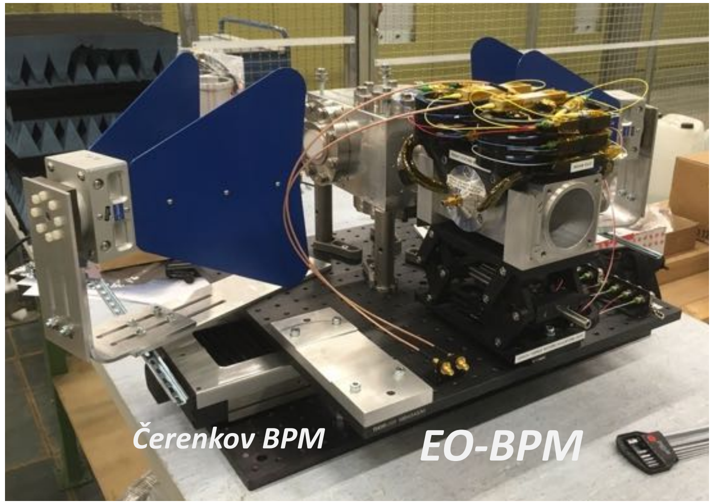
Compact fibre-coupled waveguide pick-up

EO-BPM manufacture & VNA tests at RHUL





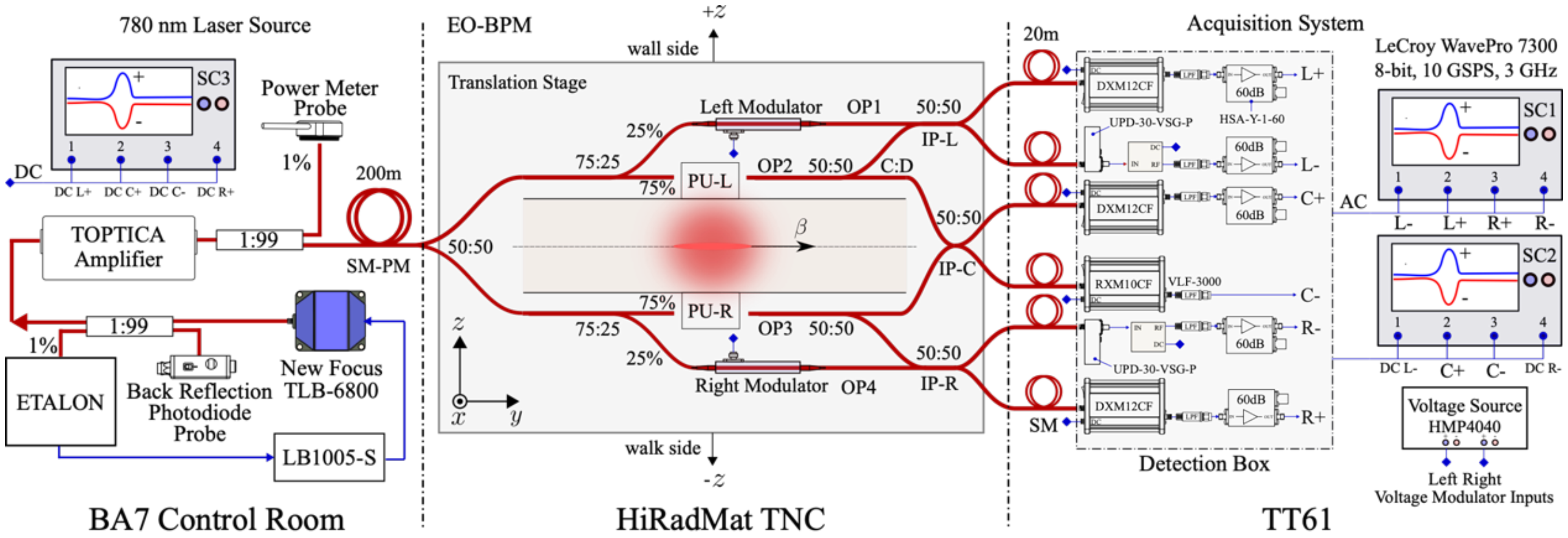




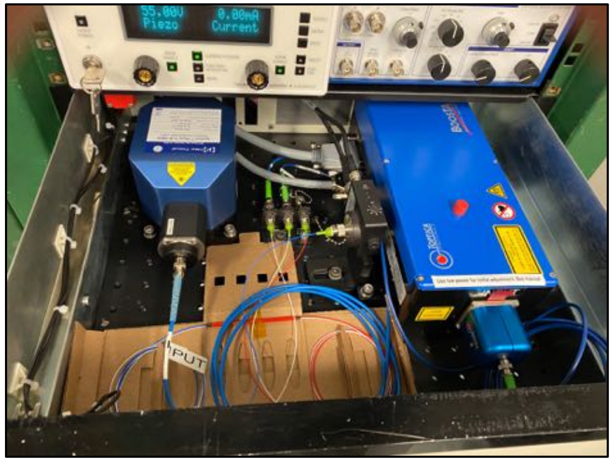
EO-BPM reception tested at CERN and laser-aligned with dielectric BPM on shared translation table

EO-BPM installation in HiRadMat facility

A. Arteche,
S. Gibson et al



780nm laser source in BA7



EO-BPM at HiRadMat extraction line

Acquisition system:

EO-BPM installation in HiRadMat facility

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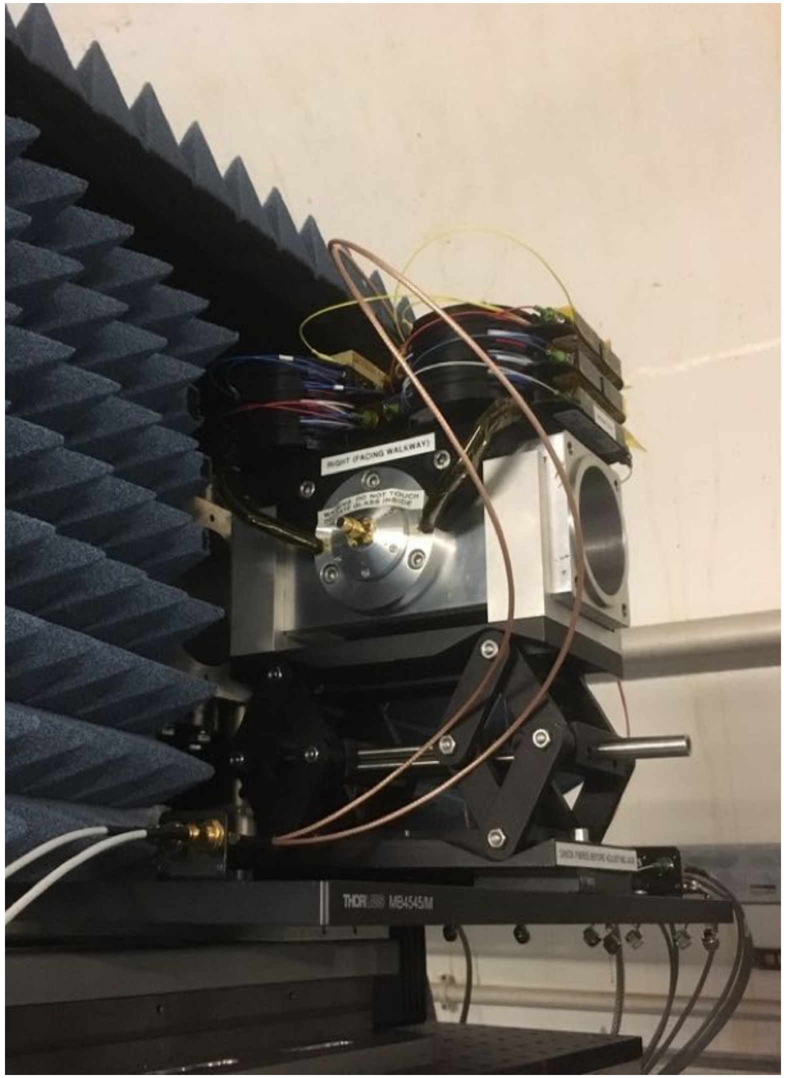
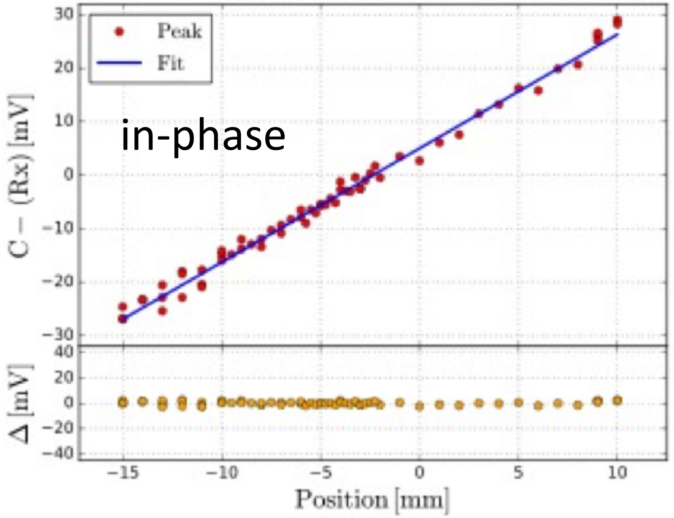


Successful first beam test at HiRadMat

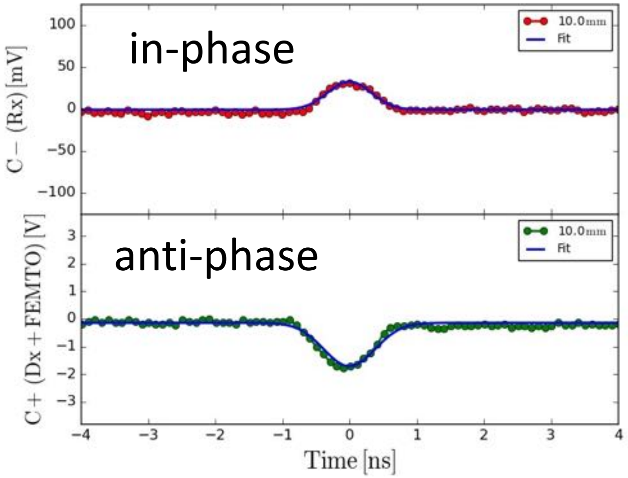
A. Arteche,
S. Gibson et al

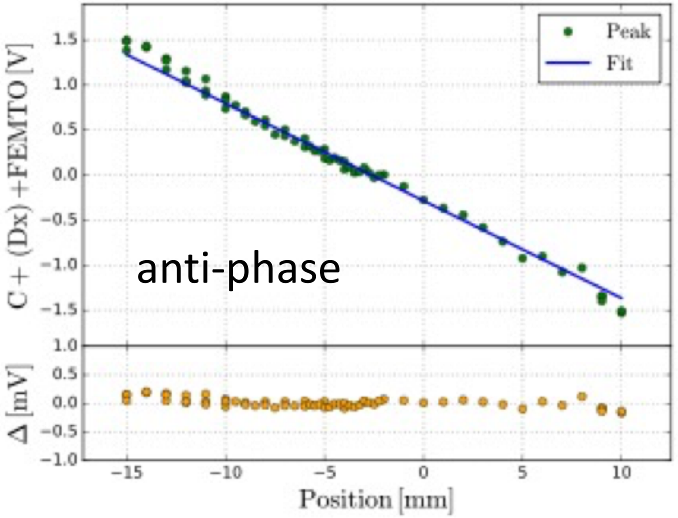
- **Waveguide design** enabled **first single-shot measurements of each passing bunch**.
- EO-BPM also **sensitive to low intensity bunches**.
- Laser scanning technique developed to **automate operation** of electro-optic interferometer.
- Translation of EO-BPM across the HiRadMat extraction line: ***first bunch by bunch position measurements:***
- *Test campaign extended to 3 runs;* ***see invited talk at IBIC2022***

Beam position scan by moving EO-BPM on stage



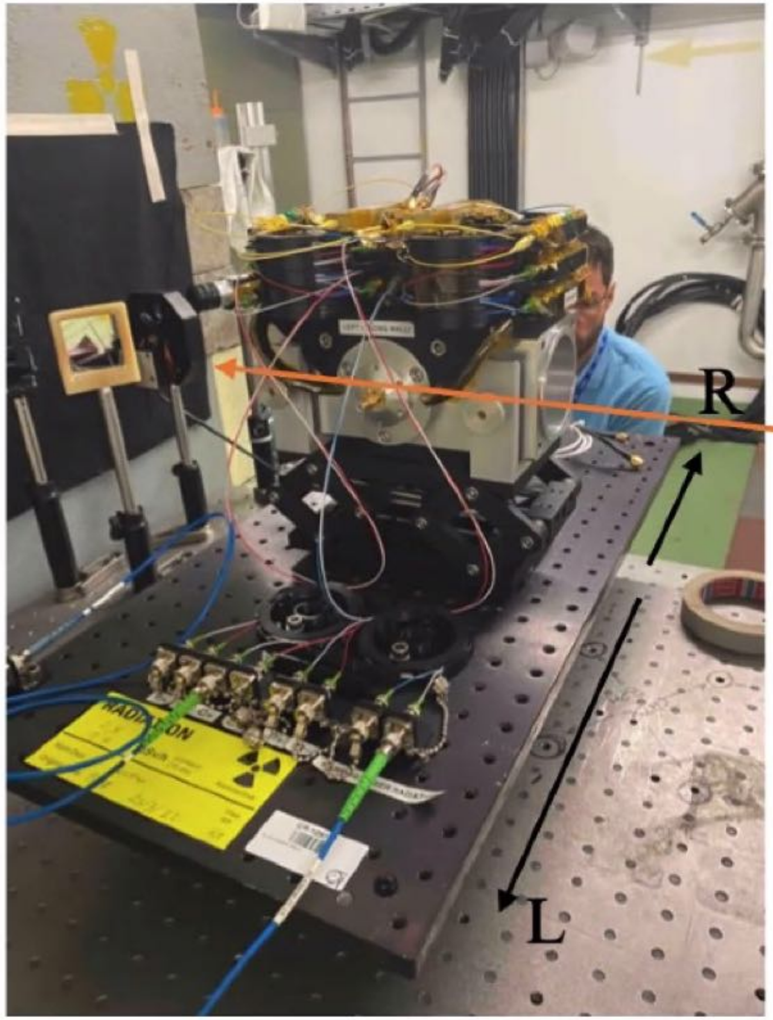
Typical single-shot signals





July 2022 EO-BPM beam test at CLEAR:

A. Arteche,
S. Gibson et al

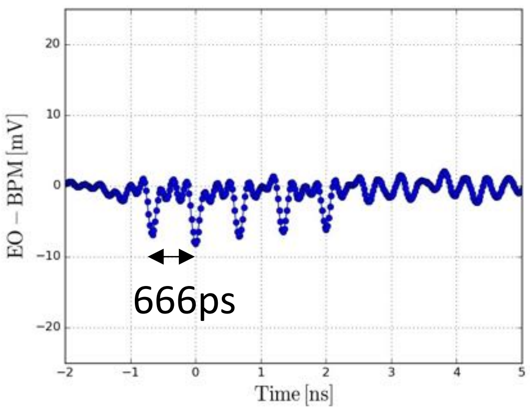


- EO-BPM installed in the CLEAR beamline to check sensitivity and ***time resolution*** to short electron bunches.

Preliminary analysis:

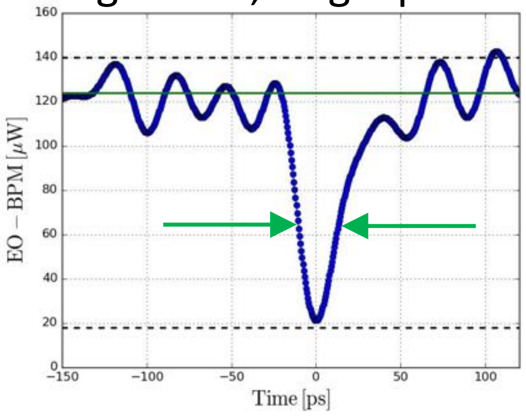
- Initial measurements of a train of 5 ***electron bunch pulses spaced by 666ps (1.5GHz) were observable*** at the photodetector, where the pulse width was limited by the bandwidth of the photodetection system.

single shot, pulse train



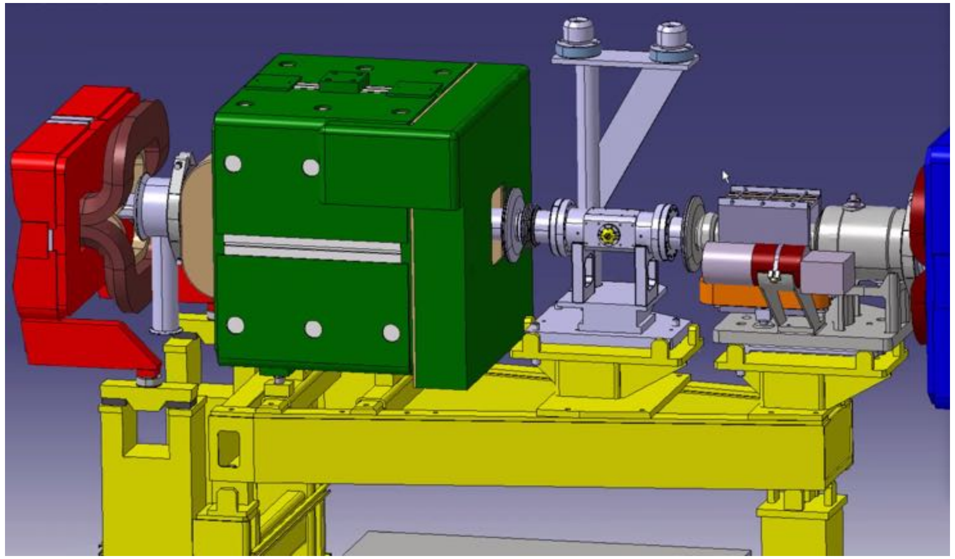
- With an upgraded detector, the pulse width indicates the time resolution of EO pick-up is well **within the < *50 ps* specification** required for the HL-LHC measurement of 1ns bunches.

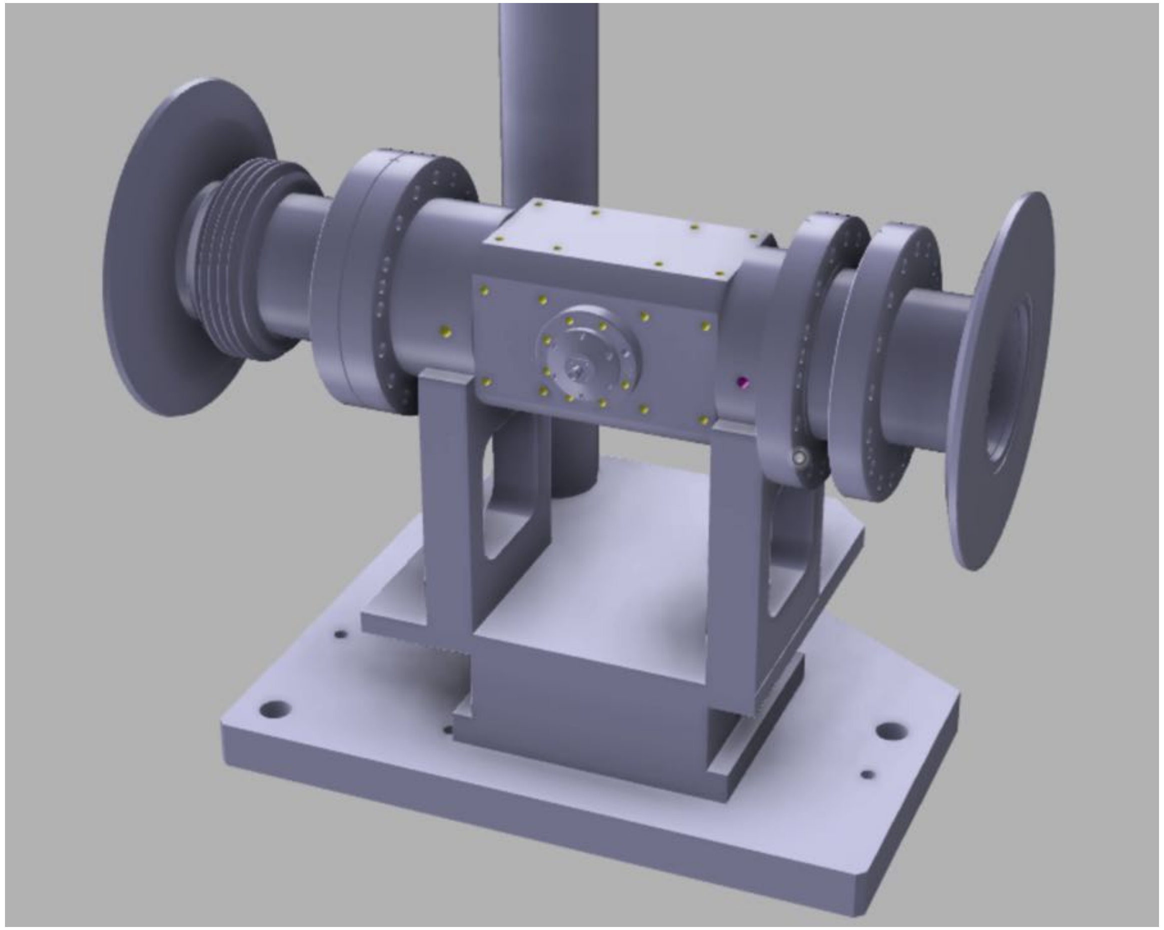
single shot, single pulse



EO-BPM future HL-LHC demonstrator in SPS

- HiRadMat EO-pick-up design incorporated into an in-vacuum design for the next phase of project.
- Excellent recent progress on CERN engineering drawings and vacuum brazing.
- **EO-BPM demonstrator** now being built for installation in **SPS** and operation in Run 3.



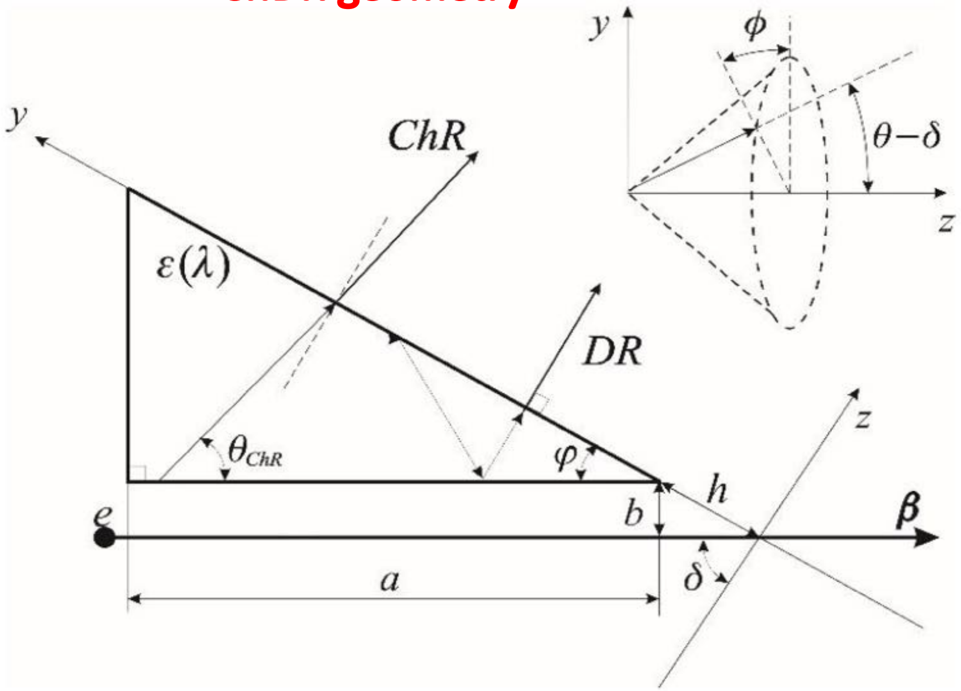


Coherent Čerenkov Diffraction Radiation

P. Karataev et al

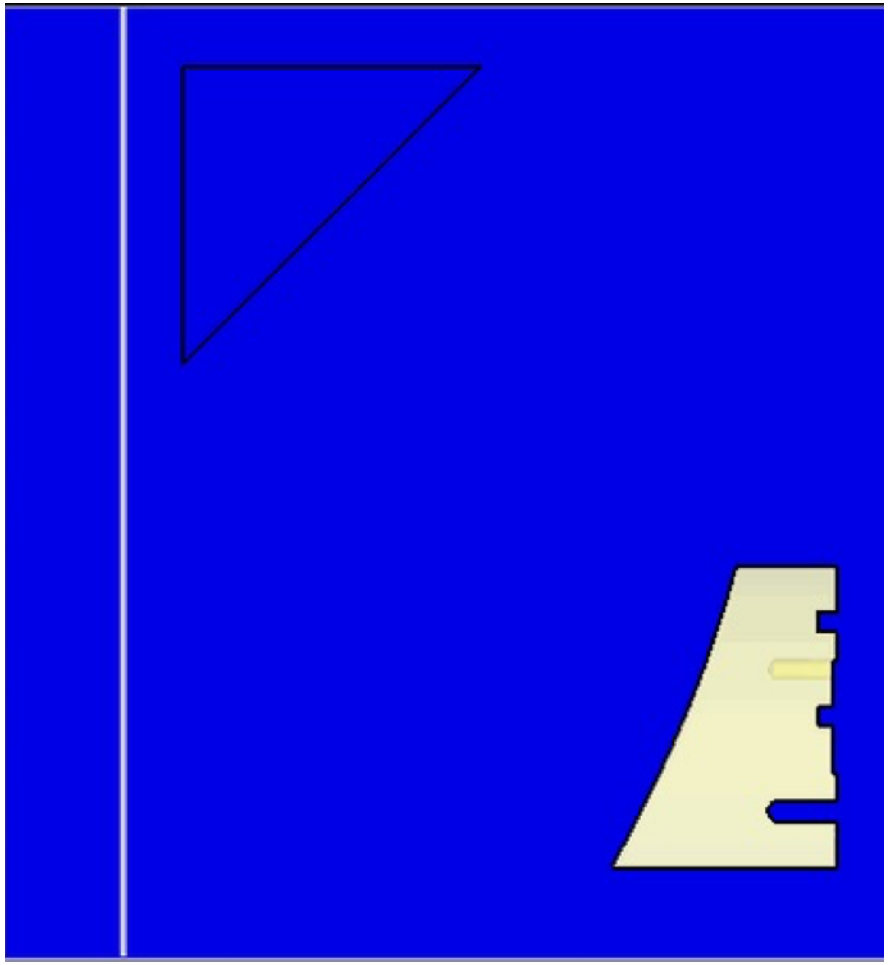
- A longitudinal bunch length monitor is under development by exploiting Čerenkov diffraction radiation, with tests performed at the CLARA facility.
- The bunch length and profile has been measured and analysed, with cross-checks at CLEAR, including EO-based readout.

ChDR geometry



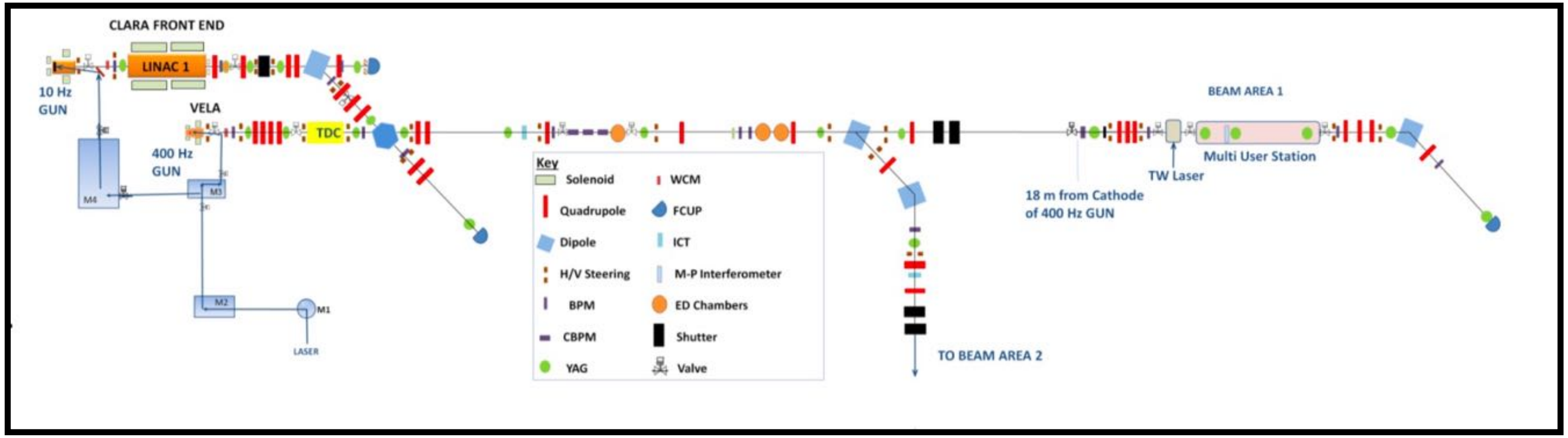
- Non-invasive diagnostic
- Relatively high intensity
- Highly directional

CST simulations



Clara layout and experimental arrangement

K. Fedorov, P. Karataev



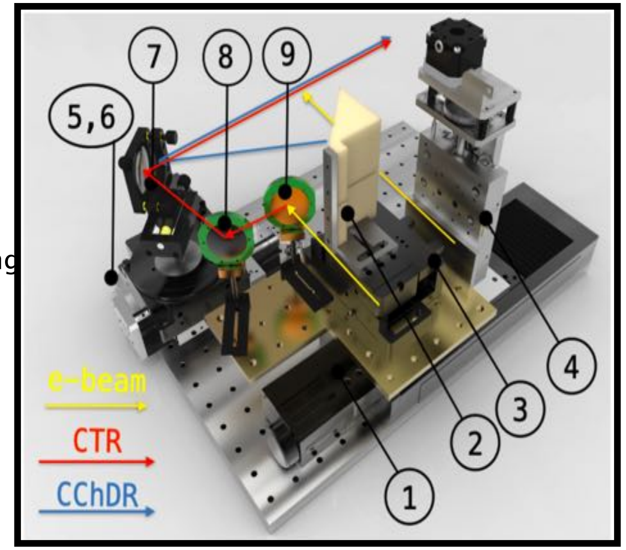
Parameters:

Repetition frequency ≈ 10 Hz
Bunch lengths ≈ 500 fs
Energy ≈ 35 MeV
Charge ≈ 50 pC
Transverse size ≈ 200 um

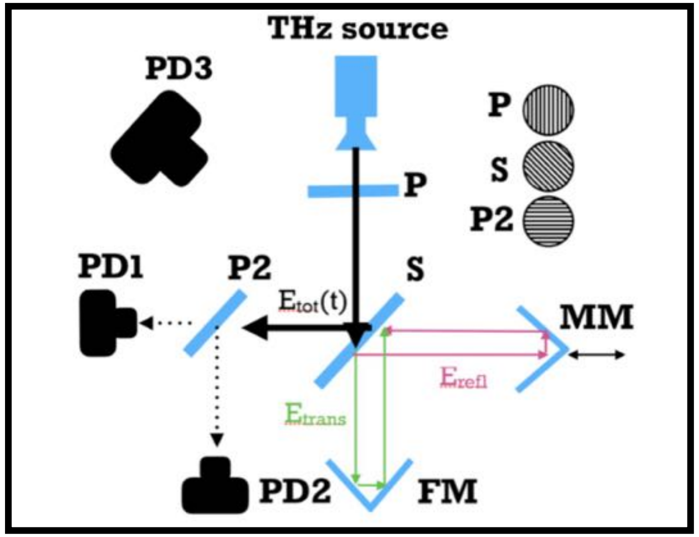
Vacuum chamber

Target assembly

1 — Horizontal positioning stage
2 — Teflon (VCR) target
3 — Tip-Tilt stage
4 — Vertical positioning stage
5 — Concave mirror
6 — mirror
7 — Foil (TR) target



Martin – Puplett interferometer



Non-invasive beam instrumentation exploiting Coherent Cherenkov Diffraction Radiation

- *A. Curcio, M. Bergamaschi, R. Corsini, W. Farabolini, D. Gamba, L. Garolfi, R. Kieffer, T. Lefevre, S. Mazzoni, K. Fedorov, J. Gardelle, A. Gilardi, P. Karataev, K. Lekomtsev, T. Pacey, Y. Saveliev, A. Potylitsyn, and E. Senes, Noninvasive bunch length measurements exploiting Cherenkov diffraction radiation, Phys. Rev. Accel. Beams* ***23*** *(2020) 022802.*

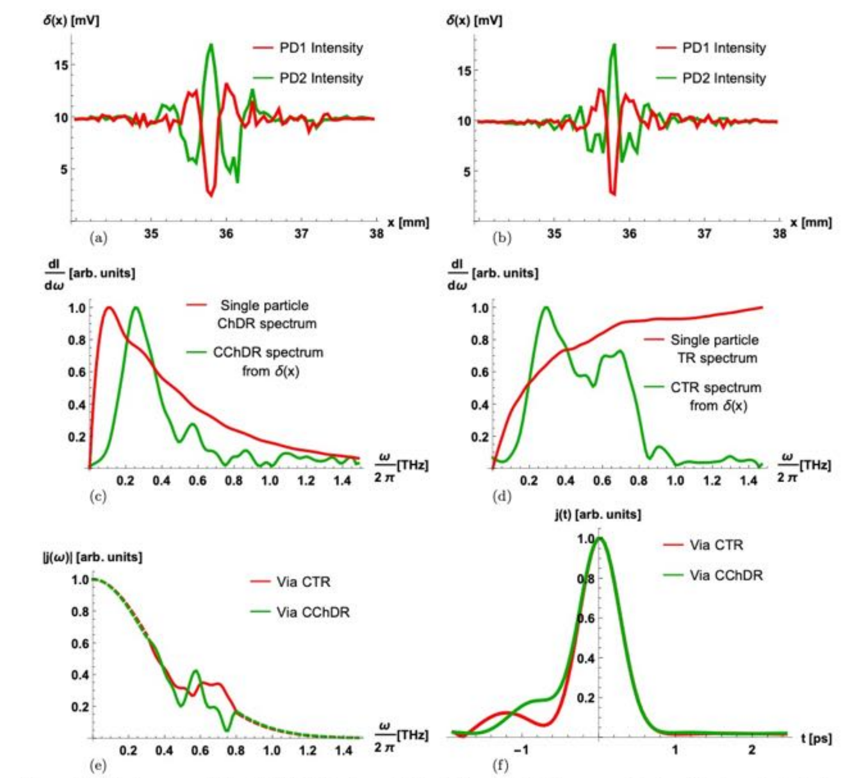


Figure 12. Interferograms of the CChDR diffraction radiation (a) and CTR (b) measured by two detectors; single electron (red) and spectra of CChDR (c) and CTR (d) derived from the corresponding interferograms; (e) is the extrapolated $|j(\omega)|$ for both CChDR and CTR; (f) is the bunch profile reconstruction via CChDR and CTR for the same accelerator settings.

CLARA

CLEAR

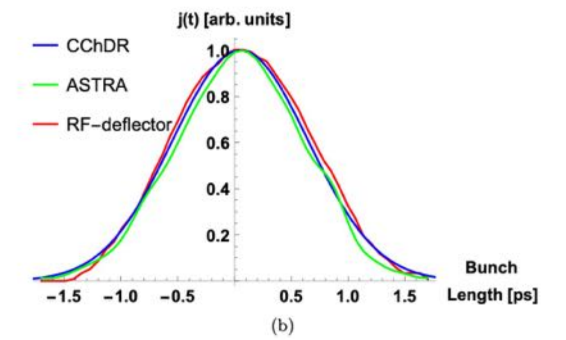


Figure 9. Top figure (a): Direct comparison between the rms bunch length of Gaussian bunches as measured with the RF-deflector and by detection of CChDR. Simulation results are also reported. Bottom figure (b): Comparison among bunch profiles obtained with CChDR, with RF-deflector and simulated with ASTRA, corresponding to the bunch length ~ 0.6 *ps* rms in Fig. 9(a).

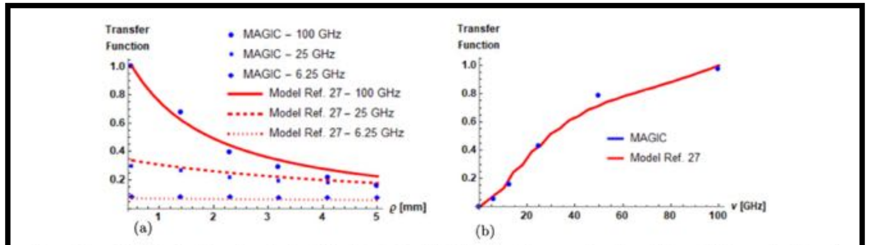


Figure 4. a: Transfer function of conical radiator ($\varepsilon = 2.1$) with internal radius ϱ ranging from 0.5 *mm* to 5 *mm*. b: Transfer function of the hollow conical radiator ($\varepsilon = 2.1$) as a function the radiated frequency.

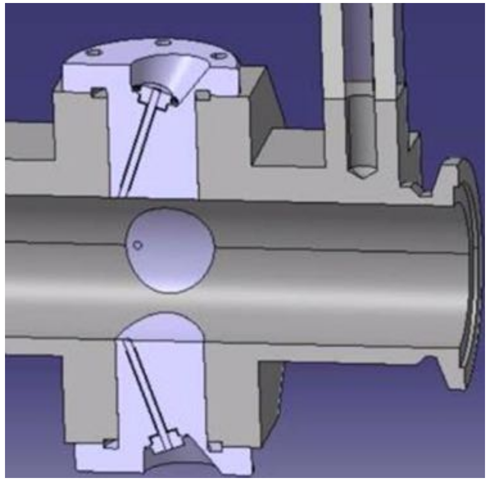
K. Fedorov, P. Karataev, Y. Saveliev, T. Pacey, A. Oleinik, M. Kuimova, and A.Potylitsyn, Development of longitudinal beam profile monitor based on Coherent Transition Radiation effect for CLARA accelerator, Journal of instrumentation, JINST 15 C06008 (2020)

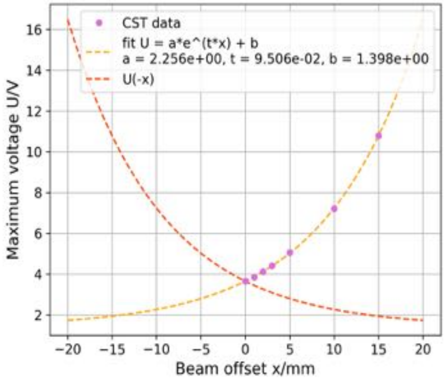
AWAKE – Čerenkov Diffraction Radiation

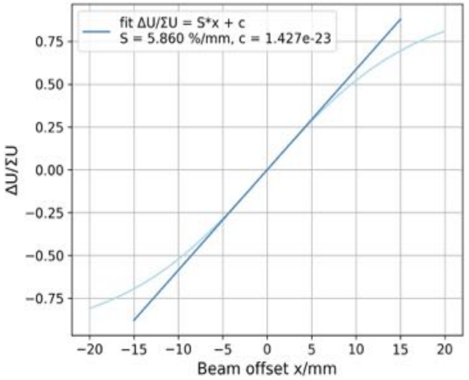
S. Mazzoni, T. Lefevre, C. Pakuza et al

See poster by Bethany Spear

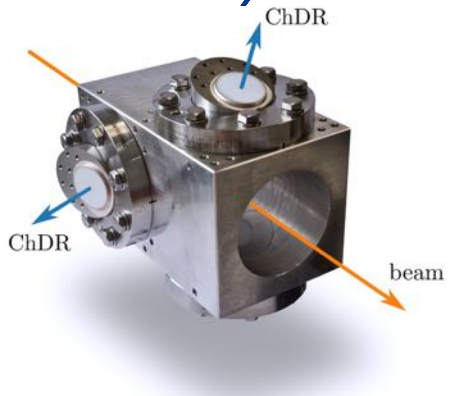
- *For e-BPM using dielectric inserts & 30GHz detection system*

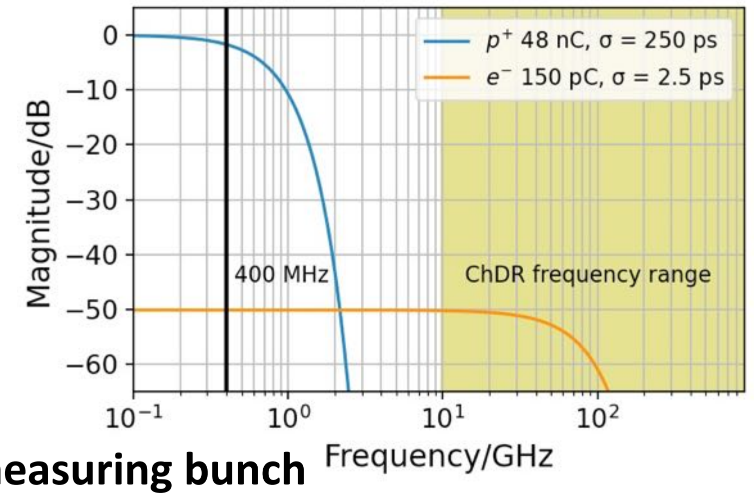




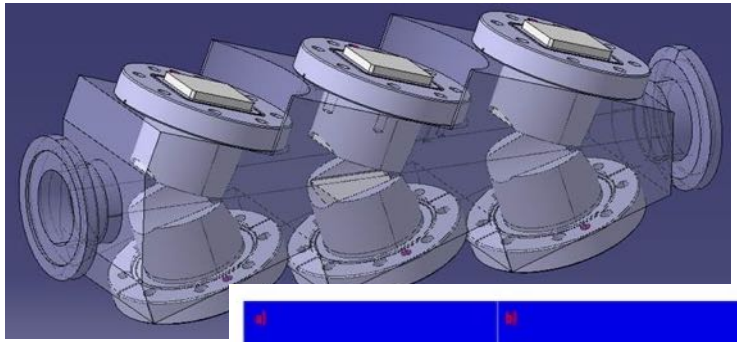


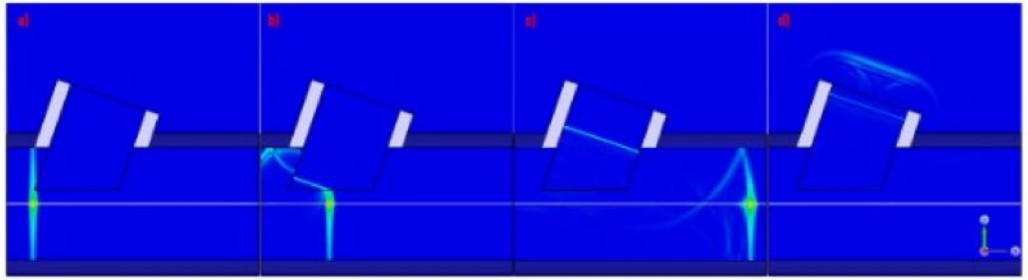
BPM behaviour as simulated in CST





For bunch length monitor measuring bunch frequency spectrum up to 1THz

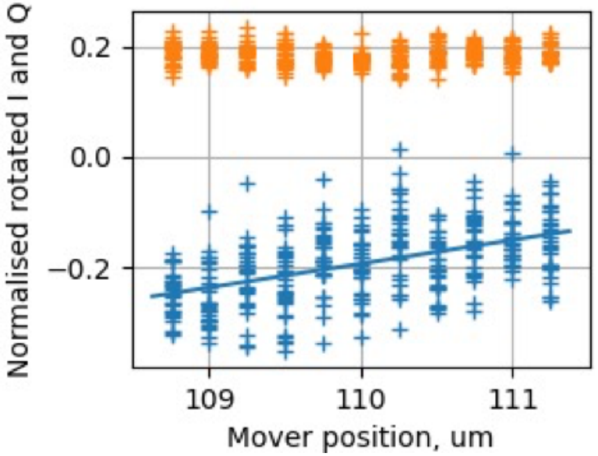




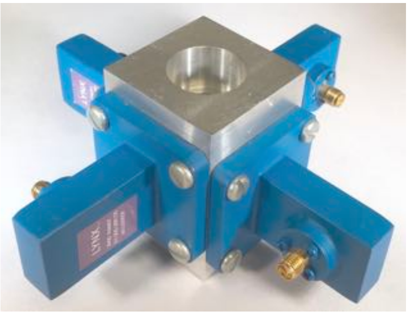
High precision BPMs and wakes

A. Lyapin

- *High resolution cavity BPMs at CLEAR*
  - 15 GHz demonstrator system for CLIC
  - Single BPM measurements successful
  - Decision for a 3-BPM test made, upgrades to a full system underway, measurement in Sept-Oct

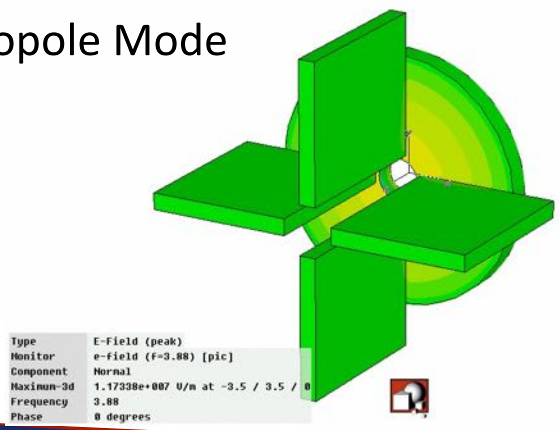


Single CBPM test with new electronics (left): 250 nm mover steps can be observed (right)

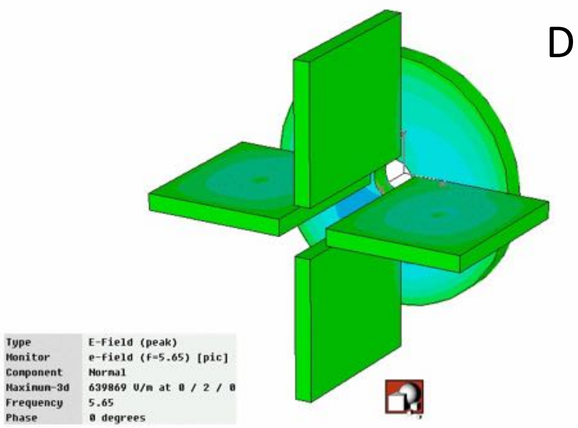


- *Waveguide BPMs*
  - Wide bandwidth
  - Design work finished, now prototyping for beam tests

Monopole Mode



Dipole Mode



Obtain signal using waveguides that only couple to dipole mode for further Monopole Supression

Recent ILC fast feedback publications

D. Bett, P. Burrows et al

UNIVERSITY OF OXFORD

PHYSICAL REVIEW ACCELERATORS AND BEAMS **25**, 022801 (2022)

High-resolution, low-latency, bunch-by-bunch feedback system for nanobeam stabilization

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(Received 14 December 2021; accepted 11 February 2022; published 22 February 2022)

We report the design, operation, and performance of a high-resolution, low-latency, bunch-by-bunch feedback system for nanobeam stabilization. The system employs novel, ultralow quality-factor cavity beam position monitors (BPMs), a two-stage analog signal down-mixing system, and a digital signal processing and feedback board incorporating a field-programmable gate array. The field-programmable gate array firmware allows for the real-time integration of up to fifteen samples of the BPM waveforms within a measured latency of 232 ns. We show that this real-time sample integration improves significantly the beam position resolution and, consequently, the feedback performance. The best demonstrated real-time beam position resolution was 19 nm, which, as far as we are aware, is the best real-time resolution achieved in any operating BPM system. The feedback was operated in two complementary modes to stabilize the vertical position of the ultrasmall beam produced at the focal point of the ATF2 beamline at KEK. In single-BPM feedback mode, beam stabilization to 50 ± 5 nm was demonstrated. In two-BPM feedback mode, beam stabilization to 41 ± 4 nm was achieved.

Jinst

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A sub-micron resolution, bunch-by-bunch beam trajectory feedback system and its application to reducing wakefield effects in single-pass beamlines

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[b] *High Energy Accelerator Research Organization (KEK), 1-1 Oho, Tsukuba, Japan*

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Abstract: A high-precision intra-bunch-train beam orbit feedback correction system has been developed and tested in the ATF2 beamline of the Accelerator Test Facility at the High Energy Accelerator Research Organization in Japan. The system uses the vertical position of the bunch measured at two beam position monitors (BPMs) to calculate a pair of kicks which are applied to the next bunch using two upstream kickers, thereby correcting both the vertical position and trajectory angle. Using trains of two electron bunches separated in time by 187.6 ns, the system was optimised so as to stabilize the beam offset at the feedback BPMs to better than 350 nm, yielding a local trajectory angle correction to within 250 nrad. The quality of the correction was verified using three downstream witness BPMs and the results were found to be in agreement with the predictions of a linear lattice model used to propagate the beam trajectory from the feedback region. This same model predicts a corrected beam jitter of c. 1 nm at the focal point of the accelerator. Measurements with a beam size monitor at this location demonstrate that reducing the trajectory jitter of the beam by a factor of 4 also reduces the increase in the measured beam size as a function of beam charge by a factor of c. 1.6.

Summary

- ***Intense hadron beams at future colliders call for novel, non-invasive beam instrumentation.***
- ***Major UK effort in the development of multiple novel beam diagnostics for the HL-LHC era and beyond, including new techniques:***
- ***Beam profile and emittance monitors:***
  - *Gas based methods: ionisation, fluorescence, vertexing*
  - *Optical methods: laserwires and synchrotron radiation*
- ***Fast beam position monitors:***
  - *Interaction region BPMs*
  - *Electro-optic BPMs*
  - *Cherenkov radiation monitors, cavity BPMs & fast feedback.*

Diagnostics posters yesterday!
Virtual diagnostic for key beam descriptors – K. Bake
Cherenkov BPMs for AWAKE – B. Spear
Gas-jet profile monitor for HL-LHC – O. Stringer
Blazed grating DMD-based diagnostics – C. Swain
Single-shot emittance measurements – J. Wolfenden

Thank you!